Is the Protection Level Afforded by AdditionalSeats Comparable to One Afforded by Approved Child-Restraints?

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Abstract

Since the introduction of the new national child restraint laws in 2010, there has been some debate regarding whether children under seven years can safely use an additional third-row seat (Vehicle Standard Bulletin 05/VSB-05, Category-2 or 3 seats) without an approved child restraint.

This study was undertaken to compare the protection level offered to children secured in an Approved Forward Facing Child Restraint (AFFCR) or a booster seat fitted on an additional seat to those seated directly on the additional seat. A typical station wagon, fitted with an additional seat, underwent a frontal crash-barrier test to investigate the interaction between the seat’s occupants and the vehicle’s interior and to assess the strength of the seat’s anchorages. Sled tests simulating frontal impacts were also performed to evaluate the protection performance of AFFCR, booster seat, child safety harness and lap-sash seatbelt used with an additional seat.

The crash-barrier test results indicated that excessive submarining occurred on the dummy seated directly on the additional seat, while the legs of the dummy restrained by the AFFCR heavily impacted the second-row seat back. Comparing the results, the risk of injury for the child sitting directly on the seat was greater than when secured in the AFFCR. While the seat anchorage performance was found acceptable, the seat latching-mechanism on the additional seat failed during the test.

This study found that current additional seats that meet the minimum requirements of VSB 05 provide less crash-protection compared to those when used with an AFFCR or a booster seat. Further research is being undertaken with the objective to improve and validate seat design and seatbelt geometry to reduce the risk of injury to the occupant. Findings from this study will be used to inform changes to VSB-05.

4. Introduction

The majority of states and territories in Australia have now implemented the new national child restraint laws which require children under the age of seven years old to be restrained in a suitable approved child restraint or booster seat. However, there is a concern that these changes will affect the use of existing after-market additional seats designed to transport children.

Some states in Australia have amended the laws allowing children aged between four and seven years to occupy these seats in a vehicle without using a child restraint or booster seat provided they are wearing the Lap/Sash (L/S) seatbelt or the lap-belt in conjunction with a Child Safety Harness (CSH).
Guidelines for the construction and installation of additional seats are provided under VSB 05A *Commercial Manufacture and Installation of additional seats* and VSB 05B *Construction and Installation of additional seats by Individuals*.

These VSBs recognise three categories of additional seats:

**Category 1** an additional seat designed and intended for use by adults. These are equipped with seatbelt anchorages and child restraint anchorages and must comply with the relevant, applicable ADRs.

**Category 2** an additional seat designed and intended for use by children up to 12 years of age or persons with a seated height less than 780 mm.

**Category 3** an additional seat designed and intended for use by children up to 8 years of age or persons with a seated height less than 700 mm.

Category 2 and 3 additional seats (referred to in this paper as *Additional Seats*) are not designed or intended for use by adults or older/larger children. The focal questions posed for this study were:

- Is it safe to use them for occupants of smaller stature such as children without the use of an AFFCR or a booster seat? and
- Is it safe to place children in an AFFCR or a booster seat in these seats?

The response to these questions is that an individual assessment for these seats in each child age group would have to be made. This is to ensure that the restraint systems distribute the crash forces as uniformly as possible on the bony structure of the child’s body.

The authors of this paper are not aware of any studies conducted to assess either the crash protection performance or the use of these seats. These seats are commonly used by child care centres transporting children on excursions.

Currently the testings and quality control over the manufacture of *Additional Seats* remains the responsibility of the seat manufacturers and/or installers. Registration authorities allow the installation of these seats into registered vehicles on the basis that they are manufactured and installed in accordance with the relevant version of the national guidelines for the manufacture and installation of additional seats: VSB 05A and VSB 05B.

From conversations with one particular seat installer, it was established that their seats were only tested once in one make and model vehicle. How the seat performs in other vehicles is unknown.

It is hypothesised that the crash protection level afforded by *Additional Seats* is less than that afforded by *Additional Seats* when used with AFFCRs or booster seats. The objectives of this study therefore were to:

a) study the kinematics and likelihood of injury to a child sitting directly in an *Additional Seat* using the existing restraint system and one restrained in an AFFCR placed on the same seat,
b) compare the crash protection performance offered by Additional Seats when used alone with the crash protection offered by those seats used in combination with an AFFCR or a booster seat,
c) compare the crash protection performance offered by Additional Seats when a child is restrained using the combination of a lap-belt and a CSH with the crash protection offered by those seats when a child used a L/S seatbelt,
d) examine if the short seat cushion depth of Additional Seats will reduce the effectiveness of the crash protection performance of a AFFCR,
e) investigate if Additional Seats would provide crash protection performance for older/larger children who are too big to use a booster seat,
f) investigate options to improve the crash protection performance of Additional Seats by altering the location of the seatbelt lower anchorage(s).

5. Methodology
A series of tests consisting of crash barrier and sled tests was performed. Table 1 summarises the test series.

5.1. Full-Frontal Crash Barrier Test
A full-frontal barrier test was conducted using a 1995 EF Ford Falcon station-wagon fitted with a Category 2 seat providing three seating positions. This vehicle type was selected since it is a vehicle that is commonly fitted with Additional Seats. The seat was purchased from and fitted by a popular Sydney installer of Additional Seats.

Testing was conducted at the NSW Centre for Road Safety’s Crashlab using two P3 dummies in the following configurations:
- One dummy was positioned directly on the Additional Seat on the driver’s side of the vehicle and restrained by the lap-only belt and a CSH that came standard with the seat. The dummy was positioned in a ‘natural’ posture, with the heels resting on the vehicle floor. In order to allow the feet to rest on the floor the dummy had to be positioned in a slouching posture (see Fig 1).
- The other dummy was restrained in an AFFCR which was fitted on the passenger’s side of the vehicle (see Fig 1).

Figure 1. Test configuration for the frontal barrier test

The test was based on the crash test specified in Australian Design Rule (ADR) 69/00 Full Frontal Impact Occupant Protection (ADR 69/00). There were some differences: The test was conducted at 48km/hr, but the vehicle mass and dummies used were tailored to suit the requirements of this test; the vehicle was ballasted to its unladen test mass, but instead of positioning two 50th percentile Hybrid-III
dummies in the second row seats as required by ADR 69/00, two P3 dummies and one child restraint were installed in the Additional Seat. The P3 dummies were chosen because there is no available dummy that represents an average four year old child.

5.2. Sled Tests

A series of 12 simulated frontal impact tests were conducted at Crashlab using a rebound sled. A category 2 seat purchased from a seat installer was used in these tests. The seat was reinforced in order to maintain its structural integrity during the tests which then mounted to the crash sled.

The same test setup was used in each test. The test matrix describing the test configurations is included in Table 1.

Table 1. Test matrix

<table>
<thead>
<tr>
<th>Test No</th>
<th>Objectives</th>
<th>D/S Dummy</th>
<th>D/S dummy's restraint</th>
<th>P/S Dummy</th>
<th>P/S dummy's restraint</th>
<th>Lower seatbelt anchorage</th>
</tr>
</thead>
<tbody>
<tr>
<td>B100008</td>
<td>a P3</td>
<td>Lap-belt with CSH</td>
<td>P3 AFFCR</td>
<td>Original</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S110002</td>
<td>b, d P3</td>
<td>AFFCR (Turn a Tot)</td>
<td>-</td>
<td>Original</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S110003</td>
<td>b, d P3</td>
<td>AFFCR (Safety 1&quot;)</td>
<td>-</td>
<td>Original</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S110004</td>
<td>b, c P3</td>
<td>L/S seatbelt</td>
<td>P3 Lap-belt with CSH</td>
<td>Original</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S110005</td>
<td>c, e P6</td>
<td>L/S seatbelt</td>
<td>P6 Lap-belt with CSH</td>
<td>Original</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S110006</td>
<td>e, P10 L/S</td>
<td>L/S seatbelt</td>
<td>P10 Lap-belt with CSH</td>
<td>Original</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S110007</td>
<td>d P6</td>
<td>AFFCR (Meridian)</td>
<td>-</td>
<td>Original</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S110298</td>
<td>b, c, f P6</td>
<td>ASC booster seat with L/S seatbelt</td>
<td>-</td>
<td>Original</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S110299</td>
<td>b, c, f P6</td>
<td>Foam booster seat with L/S seatbelt</td>
<td>P6 Foam booster seat with CSH</td>
<td>Original</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S110300</td>
<td>b, c, f P6</td>
<td>Booster cushion with L/S seatbelt</td>
<td>P6 Booster cushion with CSH</td>
<td>Original</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S110301</td>
<td>f P3</td>
<td>L/S seatbelt</td>
<td>P3 Lap-belt with CSH</td>
<td>Altered</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S110302</td>
<td>e, f P6</td>
<td>L/S seatbelt</td>
<td>P6 Lap-belt with CSH</td>
<td>Altered</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S110303</td>
<td>e, f P10 L/S</td>
<td>L/S seatbelt</td>
<td>P10 Lap-belt with CSH</td>
<td>Altered</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Driver Side (D/S), Passenger Side (C/S), Anti Submarining Clip (ASC).

The test sled and seat was calibrated to achieve a velocity change of 49 km/h and a peak deceleration of 27 g. This pulse represents the test severity required for frontal testing in AS/NZS 3629.1 *Methods of testing child restraints – Dynamic testing.*

Six high speed cameras were used to capture dummy motion. All of the cameras were mounted off-board and stationary with one on the impact block to provide a frontal view, one provided a 90° right hand side view, one a right hand side frontal oblique view, one at a 90° left hand side view, one a left hand side frontal oblique view and one provided an overhead view.

To allow for high speed film analysis, targets were placed at the seat bight (i.e. the junction of the seat back and cushion) and at the maximum head space for Category 3 seat. Targets were also attached to each dummy at the head’s centre of gravity, the centre of the palm and at the pivot point of the knee.

Two lines were drawn perpendicular to the seat movement on the sled surface: one line was 500 mm from the seat bight, representing an approximation of the distance between the seat bight to the minimum leg space on VSB 05 (white line); the other line (black line) represents the dummy’s foot forward boundary.
To better represent the range of children allowed to use these seats, three dummies were used in these tests. They represented an average three-year-old child (P3), an average six-year-old child (P6), and an average 10-year-old child (P10).

![Target Configurations]

Figure 2. Target Configurations

The dummies were dressed with tight clothing to better observe the submarining (a phenomenon where the torso slips under the lap-belt) of the dummy. Submarining was assessed visually using the high speed footage based on the presence of upward motion of the lap-belt during the impact phase.

Three different types of booster seats were used. One booster seat incorporating an anti-submarining clip (ASC) was chosen from the best booster seat listed in the 2011 Child Restraint Evaluation Program (CREP) brochure. The other booster seats - a foam booster seat and a booster cushion - were randomly selected.

Three different models of AFFCR were used; a Turn a Tot, a Safety 1st and a Meridian. The Turn a Tot was chosen because it has a very deep base that might not fit properly on Category 2 or 3 seat cushions. The Safety 1st was selected because it has been found to have the farthest base excursion during recent CREP testing, with the greatest chance of extending past the front of the short seat cushion. The Meridian was randomly selected.

All restraints were attached to the test seat in accordance with the manufacturers’ instructions and the requirements of AS/NZS 3629.1. The dummies were fitted in the restraints in accordance with the restraint manufacturer’s instructions.

Some submarining counter-measures were included in these tests. These include the use of booster seats, booster cushions and alteration to the location of the lower anchorages for the lap portion of the seatbelt. In this case, the lower anchorages were moved 100 mm forward from the original position to provide a steeper lap-belt angle and reduce the likelihood for the lap-belt to slip off the dummy’s pelvis and penetrate the abdomen.

In this study, the submarining phenomenon is divided in 3 categories:
- no submarining: this occurs when the lap-belt appears to remain visible during impact stage,
• moderate submarining: this occurs when the lap-belt appears to load into the abdomen area but has not loaded the dummy’s spinal cable,
• excessive submarining: this occurs when the lap-belt appears to penetrate the dummy’s abdomen and loads the dummy’s spinal cable.

6. Results

6.1. Full-Frontal Crash Barrier Test

The dummy occupying directly on the Additional Seat and restrained by the lap-belt and CSH experienced excessive submarining with the lap-belt penetrating the abdomen (see Fig 3 left). This type of submarining can be associated with life threatening or fatal abdominal injuries and/or serious lumbar spine injuries. Both legs of the dummy contacted the back of the seat in front but this impact was not sufficient to permanently deform the seat back. The dummy’s chin impacted its chest and the back of the dummy’s head impacted the head restraint upon rebound.

Figure 3. The point of maximum head forward excursion for P3 dummies seated directly on a category 2 seat (left) and on an AFFCR (right).

The dummy restrained in the AFFCR seemed well restrained by the 6-point in-built harness. However both legs heavily impacted the top edge of the back of the seat in front. This contact was forceful enough to permanently deform the seat back. There were chalk marks indicating glancing contact of the dummy’s head on the seat back and the dummy’s thighs (see Fig 3 right). Furthermore, results from the head acceleration data show the dummy had a HIC$_{36}$ of 1360 which appears to be from rotation of the head and this is common in Australasian New Car Assessment Program (ANCAP) tests. It was concluded that the child in AFFCR would suffer no head injury but would be at risk of a non-life threatening lower leg and/or knee injury.

Had the distance between the seats been greater, this impact with the front seat would have been avoided.

Another finding is that during the crash test the Additional Seat did not completely release, however, one of the two seat catches that connects the seat base to the rear anchorages had released and allowed further forward motion of the seat.

Results from the above test indicated that:
Neither of these two options is desirable for optimal safety of the child occupant. However, comparing the two options, the risk of injury for the child restrained in the Additional Seat using the lap-belt and the CSH is likely to be much greater than for the child in the AFFCR.

### 6.2. Sled Tests

This study focuses on the ability of Additional Seats to prevent submarining in frontal crashes. For ease of presentation of the results, the submarining observations for each test are summarised in Table 2.

#### Table 2. Submarining observation

<table>
<thead>
<tr>
<th>Test No(s)</th>
<th>P3</th>
<th>P6</th>
<th>P10</th>
</tr>
</thead>
<tbody>
<tr>
<td>S110002</td>
<td>No submarining</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>S110003</td>
<td>No submarining</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>S110007</td>
<td>--</td>
<td>No submarining</td>
<td>--</td>
</tr>
<tr>
<td>S110004</td>
<td>No submarining</td>
<td>Moderate submarining</td>
<td>Excessive submarining</td>
</tr>
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<td>S110005</td>
<td>No submarining</td>
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<tr>
<td>S110007</td>
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<td>Moderate submarining</td>
<td>Excessive submarining</td>
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<tr>
<td>S110029</td>
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<tr>
<td>S110300</td>
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<td>Excessive submarining</td>
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</tr>
<tr>
<td>S110303</td>
<td>No submarining</td>
<td>Moderate submarining</td>
<td>Excessive submarining</td>
</tr>
</tbody>
</table>

#### 6.2.1. Comparing Additional Seats with dummies using the existing restraint systems with those used in combination with AFFCR or booster seats

When a P3 dummy was restrained directly on the seat using either L/S seatbelt or CSH compared to the one restrained in an AFFCR, submarining was not observed in either case (Figs 4a and b). The test footage also shows that the head of the P3 dummy when restrained in AFCRS is still within the head space provided and without excessive upward excursion.

![Figure 4. Point of maximum femur excursion for P3 dummies restrained by L/S seatbelt (a) and AFFCR (b).](image-url)
When the P6 dummy was restrained directly on the seat using a L/S seatbelt a moderate submarining occurred (Fig 5a), but it did not occur when the dummy was restrained using a foam booster seat (Fig 5b) or an ASC booster seat (Fig 5c).

The head of the dummy when restrained in these two booster seats is also still within the space provided. However, in both cases the dummies' legs have exceeded the forward boundary.

**Figure 5.** Point of maximum femur excursion for P6 dummies restrained by L/S seatbelt (a), foam booster seat (b) and ASC booster seat (c).

### 6.2.2. Comparing Additional Seats with dummies restrained using a L/S seatbelt and when using the combination of a lap-belt and a CSH

In Figures 6a to 6d, the use of lap-belt with CSH and L/S seatbelt in P3 and P6 dummies is presented. No submarining was observed in P3 dummies when restrained in both L/S seatbelt and lap-belt with CSH. Moderate submarining was observed in P6 dummies when restrained both in a L/S seatbelt and a lap-belt with CSH.

**Figure 6.** Point of maximum femur excursion for P3 dummies restrained by CSH (a) and L/S seatbelt (b); and P6 dummies restrained by CSH (c) and L/S seatbelt (d).

This shows that the use of both L/S seatbelt and lap-belt with CSH is able to prevent submarining in P3 dummies without to use AFFCRs or booster seats. However, results obtained from the sled tests differ with the one obtained from the barrier test where the P3 dummy subarined excessively. This difference was attributed to the way the dummies were seated. In the barrier test the P3 dummy was positioned in slouching position to simulate the real world case while in sled tests the P3 dummies were seated in upright position with legs dangling on the seat edge.
P6 dummies were experiencing moderate submarining when seated in the Additional Seat restrained both with L/S Seatbelt and lap-belt with CSH.

In this regards both L/S seatbelt and lap-belt with CSH, when used in the Additional Seat, were performing in similar manner.

6.2.3. Would the short seat cushion depth of Additional Seats reduce the effectiveness of the crash protection performance of an AFFCR?

Figures 7 (a) and (b) show the still images of P3 dummies restrained in two models of AFFCR at the maximum excursions of dummies’ femur. As seen, the AFFCR with a long base (Turn a Tot, Fig 7a) is still able to maintain its forward excursion with very negligible downward rotation on the relatively short seat cushion. As was predicted, the AFFCR with the farthest excursion (Safety 1st, Fig 7b) had its base extended pass the front of the seat cushion. A similar excursion was also observed in CREP. However, the front of the restraint’s base had passed the forward boundary meaning that the base with the dummy’s legs would have impacted the seat in front.

These results demonstrate that had the leg space been wide enough, the short seat cushion of Additional Seats could be able to maintain the effectiveness of AFFCRs.

(a)    (b)

Figure 7. Point of maximum femur excursion for P3 dummies restrained by AFFCR No 1 (a) and AFFCR No 2 (b)

6.2.4. Would Additional Seats provide crash protection for older/larger children who are too big to use a booster seat?

When P10 dummies were restrained using a L/S seatbelt and a lap-belt with CSH, both dummies experienced excessive submarining with the lap-belts penetrating deep into their abdomens and loading their spinal cable (see Figs 8a and b). This excessive submarining resulted from the lap-belts riding up onto the dummies’ abdomen prior to the impact. The lower seating position relative to the floor compounded with the short leg distance raised the dummy’s thighs to approximately 45 degrees lifting the lap-belt over the dummy’s pelvis (see Figs 9 a and b).
6.2.5. Options to improve the crash protection performance of Additional Seats.

In cases where the location of the seatbelt lower anchorages were altered, there was no sign of submarining observed in P3 dummies restrained directly on the seat using both L/S seatbelt and CSH (Fig 10a) and in P6 dummy restrained using L/S seatbelt (Fig 10b). The P6 dummy did however submerge when it was restrained using a combination of a lap-belt and a CSH. The altered seatbelt geometry resulting from the relocated anchorages made no difference to P10 dummies when restrained both by L/S seatbelt and CSH (Figs 10c). These results show that altering the lower seatbelt anchorage locations has a diminishing benefit in reducing submerging as occupant size increases.
The use of both foam and ASC booster seats in combination with either L/S seatbelt or lap-belt with CSH was observed to prevent submarining (Figs 5b and c). The lap-belts remained visible throughout the impact stages. The use of a booster cushion only prevents submarining if used in combination with L/S seatbelt but when used in conjunction with lap-belt and CSH it exhibited excessive submarining (Figs 11a and b).

![Figure 11. Point of maximum femur excursion for TNO P6 dummies restrained by booster cushion with L/S seatbelt (a) and CSH (b).](image)

4. Discussion

4.1. Key findings

After-market Additional Seats provide better crash protection to a dummy when seated in an AFFCR or a booster seat compared to a dummy restrained by a L/S seatbelt or a lap-belt with CSH. The inherit design deficiency of these seats in which the seating position is low relative to the floor compounded with the short leg space will cause the lap-belt to be positioned on the dummy’s abdomen prior to an impact. This consequently increases the risk of abdominal injuries in a crash.

The results of this study indicated that the effectiveness of AFFCRs and booster seats used in Additional Seats would have been similar to their effectiveness in standard vehicle seats only if the spacing between Additional Seat and the seat in front of them were similar to the spacing between a standard or unmodified vehicle’s front and rear row of seats. The use of an AFFCR in the existing design of Additional Seats increases the risk of head and lower extremity injuries to the occupants in event of a crash.

The results of this study also show that Additional Seats do not provide crash protection to older/larger children or at least protect them from submarining without the use of an AFFCR or a booster seat.

Attempts were made to reduce the submarining potential by relocating the seatbelt lower anchorage. The results were discouraging as they were adversely affected by the short distance between the Additional Seats and the vehicle’s original rear row of seats.
4.2. Implications
These results have clear implications for the current recommended practice for using the existing after-market *Additional Seats*. The results indicate that unless substantial changes are made to the existing designs and requirements of *Additional Seats*, there is an increased risk of abdominal, head and lower extremity injuries to children occupying these seats compared to children occupying suitable child restraints in standard unmodified vehicle’s seats in the event of a crash.

However, the results of this study might not be applicable to the third row additional seats that are fitted by the vehicle manufacturer as an Original Equipment Manufacturer (OEM) which are commonly fitted to some models of four-wheel-drive vehicles. In this case, the recommended practice is to follow the vehicle manufacturer’s instruction for their use.

4.3. Limitations
The results presented in this paper are made from observations of two models of *Additional Seats*, one vehicle, three AFFCRs, two booster seats and one booster cushion. Other *Additional Seat* in other vehicle and/or child restraint models may behave differently.

5. Conclusions
Based on the risk of submarining, results from this study suggest that in frontal impact, children aged between four and seven years seated in the after-market *Additional Seats* are better protected using either an AFFCR or a booster seat rather than using the L/S seatbelt or lap-belt with CSH alone. However, based on the risk of head and lower extremity injuries, the use of an AFFCR and a booster seat in *Additional Seats* is only recommended if the distance between the seats is similar to the distance between the second row seat and the front seat. Results from this study also suggest that older children not using booster seats would have an increased risk of excessive submarining when occupying the current design of *Additional Seats* available.

Further research into the design of the *Additional Seats*, including the head and leg spaces, seat cushion length, seatbelt anchorage positioning, use of an anti-submarining pan and appropriate cushion foam density, is required to optimise safety of children using them, and ultimately be included in the rewrite of VSB 05.