Introduction

There are many aftermarket child restraint accessories available on the Australian market, such as the gated buckle (used to convert a lap/sash belt to a lap only belt) and the chest strap (connects to the harness straps to make it harder for a child to remove their arms). These products are often perceived as serving a safety need, such as the chest strap preventing a child from removing their arms from a harness and being partially unrestrained. However, it is unknown if these products interfere with the safety performance of the restraint or present a hazard in themselves. This research explored whether adding either a gated buckle or chest clip to a child restraint affects the performance of the restraint or presents a safety hazard in the event of a crash. A test protocol was developed and dynamic testing was subsequently performed to determine whether any safety implications existed for two specific aftermarket child restraint accessories - the gated buckle and chest strap. The gated buckle was tested on both rearward and forward facing child restraints, while the chest strap was tested on a forward facing child restraint only. The results were compared to baseline dynamic test results that were performed without the accessory. This report outlines the dynamic assessment process and discusses the safety implications or potential hazards resultant from the use of these devices. Recommendations around the use of these devices are also discussed.

1.0 Background

There are various aftermarket child restraint accessories that are commonly used by parents. These devices are often used with the intent of improving child safety when travelling in a vehicle. In 2012, RACV commissioned research to undertake a desktop review of a variety of these accessories (Paine, Paine, Brown & Bilston, 2012). This work identified that many accessories had potential safety risks. Two of these devices, the gated buckle and the chest clip, warranted further investigation.

The gated buckle is a device that is designed to convert a lap/sash seatbelt into a lap only belt. It is generally used to provide a tight, secure installation of the child restraint and to ensure the restraint remains in the installation position throughout ongoing use. Previous RACV research identified that depending on how it is used, it may allow excess slack in the lap section of the belt and that it could also come into contact with the child in the event of a crash (Paine et al, 2012). There are also concerns that in a crash it may become unthreaded from the seatbelt or break, and act as a projectile.

The chest clip is designed to prevent the child restraint occupant from taking the shoulder straps off their shoulders by clipping the two shoulder straps together across the chest. However, in the event of a crash,
depending on how it is positioned, there may be a risk of choking, strangulation, injury to the throat or chest. Use of this device may also make it more difficult or time consuming to remove a child from the vehicle in an emergency. However, without conducting dynamic testing to further understand the potential hazards of these devices, it is difficult to establish whether these theoretical risks are realistic, and hence whether these devices are fit for use in a real world scenario (Paine et al, 2012).

Although the voluntary Australian Standard AS/NZ 8005:2013 Accessories for child restraints for use in motor vehicles was introduced in 2013 (Standards Australia, 2013), there is still very little known about whether devices meeting this standard affect the performance of a restraint detrimentally. The aim of this study was to investigate how child restraint accessories interact with a child restraint in a crash. RACV commissioned APV Tech Centre to develop a test protocol that can be used for the dynamic assessment of child restraint accessories. This protocol was subsequently used to undertake dynamic assessment of a gated buckle and chest clip to determine whether there are any potential safety implications of these devices in the event of a crash.

2.0 Methodology

There were two phases to this study. The first phase involved developing a protocol for dynamic assessment of child restraint accessories, while the second phase involved using the protocol to perform testing of two products, the gated buckle and chest clip.

2.1 Protocol Development

A protocol for dynamic assessment was prepared from relevant sections of existing standards. AS/NZS 8005:2013 - Accessories for child restraints for use in motor vehicles (Standards Australia, 2013) was used as a base and increased performance requirements were further specified to match the Child Restraint Evaluation Program (CREP) protocol where appropriate. Other recognised standards were also used; e.g. seatbelt modification devices (i.e. gated buckle) were subjected to sections of the Australian Design Rules 4/05 (Vehicle Standard, 2014) to verify the integrity of the belt would not be compromised. The protocol was reviewed by RACV Vehicle Engineers and a full protocol was finalised that will enable further testing of additional child restraint accessories to be completed independently of this research.

2.2 Gated Buckle

The gated buckle was tested using a rearward and forward facing child restraint. Table 1 outlines the specific tests that were conducted. The target impact speed for frontal tests was 56km/h and 32km/h for side tests. All tests of both the baseline (without gated buckle) and with the gated buckle were within the allowable tolerance of the target speed. The following items were purchased for use in the testing:

- Six bowed gated buckles (as shown in Figure 1).

Figure 1. A gated buckle prior to testing
The rearward and forward facing child restraints used in these tests were specifically chosen for a number of reasons. In particular, they both performed reasonably well from a safety perspective (i.e. both scored 3 stars for safety in CREP testing), and from a consumer perspective they are reasonably priced. This suggested they may be popular choices for parents. The bowed gated buckle was specifically chosen as it appeared to be the most commonly available to the public. An online store was also able to confirm that they sold significantly more bowed gated buckles as opposed to the flat gated buckle. Additionally, RACV restraint fitters perceived the bowed gated buckle to be more effective in keeping the seatbelt tensioned than the flat gated buckle.

Table 1. Tests conducted to assess the gated buckle.

<table>
<thead>
<tr>
<th>Child Restraint Direction</th>
<th>Baseline / Gated Buckle</th>
<th>Dummy Type</th>
<th>Test Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rear Facing</td>
<td>Baseline</td>
<td>TNO P1.5</td>
<td>Frontal</td>
</tr>
<tr>
<td>Rear Facing</td>
<td>Gated Buckle</td>
<td>TNO P1.5</td>
<td>Frontal</td>
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<tr>
<td>Rear Facing</td>
<td>Baseline</td>
<td>TNO P1.5</td>
<td>Perpendicular Struck Side</td>
</tr>
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</tr>
<tr>
<td>Rear Facing</td>
<td>Baseline</td>
<td>TNO P1.5</td>
<td>66° Struck Side</td>
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<tr>
<td>Rear Facing</td>
<td>Gated Buckle</td>
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</tr>
<tr>
<td>Forward Facing</td>
<td>Baseline</td>
<td>TNO P6</td>
<td>Frontal</td>
</tr>
<tr>
<td>Forward Facing</td>
<td>Gated Buckle</td>
<td>TNO P6</td>
<td>Frontal</td>
</tr>
<tr>
<td>Forward Facing</td>
<td>Baseline</td>
<td>TNO P3</td>
<td>Perpendicular Struck Side</td>
</tr>
<tr>
<td>Forward Facing</td>
<td>Gated Buckle</td>
<td>TNO P3</td>
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2.3 Chest Clip

The chest clip was tested using a forward facing child restraint only. A rearward facing restraint was not used in this testing because the issue of a child removing their arms from a harness is most common for toddlers who are in a forward facing restraint in Australia. Additionally, the chest clips are mainly marketed towards children when in forward facing mode. Table 2 outlines the specific tests that were conducted. The target impact speed for frontal tests was 56km/h and 32km/h for side tests. All tests of both the baseline (without chest clip) and with the chest clip were within the allowable tolerance of the target speed. The following items were purchased for use in the testing:

- Three Houdini Stops (as shown in Figure 2)

The child restraint was specifically chosen for a number of reasons. In particular, it performed reasonably well from a safety perspective (i.e. scored 3 stars for safety in CREP testing) and is reasonably priced, suggesting it may be a popular choice for parents. The specific chest clip was chosen as it appears to be the most widely available device in stores within Australia, and hence the most likely to be used by parents.
2.4 Dynamic Assessment Procedure

As specified in the protocol, a comparison of key measurements was made from tests with the accessories fitted to a series of baseline tests.

For each test the child restraint was mounted following the manufacturer’s instructions to a seat fixture. The top tether adjuster and seatbelt harness adjuster were both subjected to a 60-80N tensile force following the removal of slack.

Three digital high speed cameras (operating at 1000 frames per second) were utilised to capture each test. A mixture of on-board and facility mounted cameras were used. For the frontal test with the chest clip, an extra camera was added to the front left to capture head movement and potential contact with the accessory.

The sled acceleration during the pulse was measured using two accelerometers fixed at the rear of the sled then put through a Channel Frequency Class 60 (CFC60) filter compliant to Society of Automotive Engineers, SAE J211 1988 (Standards Australia, 1988). The sled velocity was measured using a raster strip mounted to the facility and two optical sensors on the sled.

During the chest clip testing, the shoulder pads were removed from the two shoulder straps of each child restraint in order to position the accessory as shown on the packaging (as no instructions on fitment height were provided). All chest clips were coated in blue and green zinc to show any interactions with the dummy. Blue zinc coated the two outer clips and green zinc coated the centre strap.

All gated buckles were fitted using the procedure provided by an RACV restraint fitter. This involved fitting the gated buckle to the retractor side of the restraint to pin the sash and lap belts together, with enough tension to fit a few fingers at the top back of the restraint, this equated to approximately 20 N through the lap belt once the gated buckle was fitted (with no occupant or weight applied).

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Table 2. Tests conducted to assess the chest clip.
3.0 Results

3.1 Gated Buckle

During the frontal test in the forward facing mode a significant increase in forward knee travel was observed when the gated buckle was fitted. This test also resulted in an increase in the head impact and decrease in the chest impact values when the gated buckle was used. The backrest of the restraint was also observed to twist more when fitted with the gated buckle (Figure 3).

Conversely, in the rearward facing frontal test the head impact value decreased and the chest value increased when the gated buckle was fitted. The backrest was also observed to twist less when the gated buckle was used during this test (Figure 4).

During all side impact tests with the gated buckle, particularly in the rearward facing mode, the child restraint travelled a shorter distance and rotation was significantly reduced after impact with the door. The dummy’s head was also contained in the child restraint for a greater period during the rear facing tests and finished within the enclosure of the child restraint for the rear facing oblique side test. Figure 5 shows, from above, the more extensive head excursion and the greater rotation of the seat without the gated buckle. The results also showed a decrease in both head and chest impact values (with the exception of the rear facing oblique side test).
The gated buckle remained attached to the seatbelt during all forward and rearward facing tests. However, the webbing did become partially unthreaded during a number of tests, as shown in Figure 6. While no gated buckles broke during testing, a number of the devices showed significant signs of deformation following testing, an example is shown in Figure 7.

Figure 5. The restraint twisted less and the head remained within the enclosure of the restraint following the gated buckle test (right) when compared to the baseline test (left), at 350ms after impact

Figure 6: The gated buckle following testing, showing the partially unthreaded belt.

Figure 7. The bent gated buckle following testing.
3.2 Chest Clip

Figure 8 shows the chest clip fitted prior to testing. The results showed a large head impact occurred during both frontal tests, with and without the chest clip. However, the head impact was significantly increased when tested with the chest clip. Video footage of the test appeared to show the dummy’s head impacting upon the seatbelt buckle and/or the dummy’s thigh during both of these tests.

During the majority of the side impact tests, severity of both head and chest impact values reduced with the addition of the chest clip. The exception to this was the perpendicular side test, which showed a very small increase in chest impact value, although this increase was not considered significant enough to overcome test variations. High speed footage of the oblique side test also showed a decrease in chest rotation during the impact point when the chest clip was fitted.

At no point during any frontal or side impact tests did the chest clip contact the occupant neck nor did the neck appear to move significantly towards the clip. The chest clip also did not slip up the harness straps. However, as can be seen in Figure 9, the chest clip was observed to make impact with the face during the frontal test, specifically, contact with where a mouth would be. As facial injuries were unable to be measured, the type or severity of any potential injuries resultant of this impact is unknown. In addition, in all tests the chest clip maintained its integrity, no items detached, and no damage was noted to the device. The chest clip was also able to be easily unclipped following all tests.

Figure 8. Chest clip in position before test.

Figure 9. Blue zinc can be seen on the dummy’s face.
4.0 Discussion

4.1 Gated Buckle

Some positive safety outcomes were observed when using the gated buckle with a rearward and forward facing restraint. There are also some small safety concerns apparent, although the severity of these concerns are unknown.

In particular, while an increase in forward knee travel was recorded as significant, the actual knee movement was not large. Therefore, there could be a small chance that this would increase occupant impact with the vehicle interior and have a negative effect upon safety. However, the type or severity of any injuries resulting from such an impact is unknown.

The contrasting head and chest impact results recorded during the frontal test for the rearward and forward facing restraints likely occurred due to the changes in dynamics between the seatbelt and top tether when using the gated buckle. For example, a modified proportion of top tether loading verses seatbelt loading appears to have resulted in the forward facing child restraint backrest twisting more when fitted with the gated buckle and the rearward facing restraint twisting less.

During all side impact tests the restraints were observed to travel a shorter distance and rotate less. Additionally the dummy's head remained within the restraint for a greater period of time during the rearward facing tests, suggesting a significant safety advantage by preventing head impact with the vehicle interior, other occupants or intrusion. Most of the side impact tests supported this improvement in safety by showing a reduction of head and chest impact results when the gated buckle was fitted. These findings are likely to be a result of the gated buckle providing a more laterally stiff lower mounting arrangement, which appeared to restrict displacement and rotation of the restraint base.

It was interesting to note that although the head finished within the restraint following the oblique side impact test this was the only rearward facing side test not to show a reduction of head and chest impact values. Despite this finding, the head finishing within the restraint following this test is considered to place the occupant of the restraint in a safer position if there are to be further accelerations or impacts. Further tests may need to be completed to understand the conflicting head and chest impact findings.

The previous RACV desktop review outlined that if the gated buckle was to be used incorrectly it may allow excess slack in the lap section of seatbelt or it could also come into contact with child. Although misuse was not investigated in this particular research, neither of these situations occurred during testing.

Despite pre-test perceptions that the gated buckle may either break or become completely unthreaded from the seatbelt, this also did not occur during testing. However, the webbing was observed to become partially unthreaded during the rearward and forward frontal tests and during the rear facing oblique side test. It may be assumed that such a situation will have a detrimental effect on any subsequent impacts. For example, it may result in excess slack of the seatbelt or in the gated buckle coming completely loose and acting as a projectile in the vehicle. However, the real world consequences of this finding are unquantified. It is recommended that further tests be conducted to verify the implications of this scenario.

The gated buckle is designed to convert a lap/sash seatbelt into a lap only belt. It is generally used to provide a tight, secure installation of the child restraint and to ensure the restraint remains in the installation position throughout ongoing use. When deciding whether to use an aftermarket gated buckle consideration should first be given to the manufactures instructions. Many restraints already come with a gated buckle or have an inbuilt 'locking clip', and hence these devices should be used where recommended by the manufacturer. Consideration should also take into account how the vehicle seatbelt interacts with the child restraint system during installation. For example, if secure installation is problematic or the restraint is becoming loose over time without a gated buckle, then the use of the device may be required.

It is important to note that these results are dependent on the specific method used to fit the gated buckle. A strict installation method that is taught throughout the RACV restraint fitter network was investigated, as was the use of a particular style of gated buckle. However, it is possible that inconsistent positioning of these devices is likely by those that have not been trained in this particular method, in which case the results may not be comparable.
The minor safety concerns identified in the frontal test with a forward facing restraint may be offset by the benefits reported in side impact crashes. For example, despite the knees being slightly more likely to come into contact with the vehicle interior in a frontal crash, it is unknown what injuries will occur as a result. Whereas in a side impact crash, an improvement in restraint and occupant positioning was observed, suggesting improved protection particularly for the head and chest. Therefore, the findings of the current study indicate that these devices can be used with some caution, taking into account the minor risk of knee/leg injury, the benefits of improved head and chest protection, and the practicality of fitting restraints appropriately.

4.2 Chest Clip

Earlier RACV research found that chest clips may pose a number of safety issues in the event of a crash, such as a risk of choking/strangulation; injury to the throat or chest (especially if the device is comprised of hard materials); and/or difficulties or additional time required to remove a child from the restraint in an emergency. The current research was unable to verify many of these concerns.

The large head impact that was recorded during the frontal tests appears to be influenced by the dummy’s head impacting the seatbelt buckle and/or thigh. Although the head impact increased from a likely serious head injury to a likely critical head injury when fitted with the chest clip, it is unclear how much of this variation can be attributed to the use of the chest clip alone. An increase in head impact of this scale was a somewhat unexpected finding, as prior to testing it was expected that the addition of the chest clip was more likely to influence the results for a chest injury rather than head injury in a frontal test.

It is possible that this finding is a result of a variation in the dummy’s head direction and speed between tests, which was observed to change slightly during the accessory test when compared to the baseline test. While the addition of the chest clip may have played a role in this variation, it is also believed to be in part due to the removal of the shoulder pads from the harness (which was required in order to secure the chest clip to the harness).

It is important to note, that because the baseline test found that a likely serious head impact already existed with the use of this particular restraint, these results may not be representative when using a chest clip with other restraints that do not already have the existing head impact during a baseline test. Further testing should be undertaken to validate such assumptions.

There appeared to be some safety benefit when using the chest clip in the event of a side impact crash, which was evidenced by improvements in head and chest impact scores for the majority of the side impact tests. The chest clip is considered to play a significant role in this finding. In particular, while the test footage did not show the shoulders coming free from the harness in any of the side tests, the likely outcome of the chest clip holding the two shoulder straps at a set distance may have prevented undesirable movement of the straps. This was specifically observed during the side oblique test, as the dummy rotated less when the chest clip was fitted. This is considered to result in better occupant retention within the restraint.

Any consequences of having the occupants shoulders free of the harness during a crash are unknown but are likely to be serious, and it is considered vitally important that the shoulder straps are kept on the occupants shoulders prior to an impact. In circumstances where children are regularly removing the harness from their shoulders the chest clip may be a benefit while this behaviour persists.

Although previous research and recommendations about using these devices highlight contact with the neck as a potential risk, the current research was unable to verify this risk. However, during the frontal test some contact between the chest clip and with the dummy’s face was observed, specifically where the mouth would be. Facial injuries of unknown severity would appear to be the most likely outcome of this contact.

The current research used a strict positioning method when fitting this device, which was considered “correctly fitted” (Figure 8). Misuse was not investigated in this research, however due to a lack of positioning instructions for this particular device inconsistent positioning is likely in the real world. This may involve the device being positioned too high on the harness, in which case undesirable contact between the device and the neck may occur. Further research would benefit from investigating misuse of these devices.
Additionally, the device was not observed to be damaged following the testing, suggesting no part of the device could act as a projectile in a crash. This fails to support the desktop findings that suggested damage to the device may result in difficulties removing the child from the restraint in the event of a crash. However, use of the chest clip is still likely to result in additional time removing the child from the restraint in an emergency, whether the device is damaged or not.

The chest clip is an aftermarket device that is intended to prevent the child restraint occupant from taking the shoulder straps off the shoulders at an incorrect time (e.g. during travel). When determining whether the chest clip is to be used, it should first be ensured that the harness straps are appropriately tightened and the restraint is being used correctly. Consideration should then be a compromise between preventing the occupant wriggling out from the restraint; fitting the device so contact with the neck is avoided; and ensuring contact with the face is avoided in the event of a frontal crash. It is also worth carefully considering the added step of needing to remove the device in the event of an emergency, as it may not be the parent or even an adult removing the child from the restraint and unfamiliarity with the device may result in unnecessary complications.

5.0 Conclusion

This research examined the safety implications of the gated buckle and chest clip. It was found that there are some situations where use of these devices is acceptable. In particular, the gated buckle may be recommended when there is a poor fit between the restraint and the vehicle, and when the restraint does not already come with a gated buckle or similar ‘lock off’ feature in-built. However, it is important to note that there is a very small chance the occupant’s legs may make contact with the vehicle interior in a frontal crash when using these devices. The use of an aftermarket gated buckle should also be in accordance with the manufactures instructions.

Chest clips are suitable for use when a child is consistently removing their arms from the child restraint harness straps and when behavioural techniques are ineffective. The clip can be used in the short term as a last resort while the behaviour persists. However, the use of this device should be cautioned, as removal of the device will result in an added step of removing the child from the vehicle in the event of an emergency.

The current research focused on the safety implications of two child restraint accessories, the gated buckle and the chest clip being used correctly. Future research may benefit from considering the safety implications of misusing these devices. Additionally, as two devices were able to be tested in the current research, follow up research may consider assessing how other types of accessories influence the safety implications of child restraints. Furthermore, in a similar style to CREP, there may be some benefit in comparing different variations of the same type of accessory and providing a rating from a safety perspective. For example, comparing a bowed style gated buckle with the flat style gated buckle.

Future research may also benefit from including a strict dummy positioning process or dimensional verification using a 3D measuring device prior to each test, which would minimise unintended variations from baseline tests.

This research has assisted in providing better knowledge on the safety of the gated buckle and chest clip device. However, there are many other child restraint accessories available on the market. Additionally, there are also many different variations of the same device. The protocol developed in the current study has been created with these other devices in mind, and can similarly be used to assess safety implications of other products.
**References:**


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