‘Best Practice’ Guidelines for the Usage of Child Safety Harnesses

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Abstract

Child safety harnesses (CSHs) have been covered by the Australian Standard for child restraints since its introduction in 1970. They can be used alone or with a booster seat. Their initial appeal was that they provided some means for upper torso restraint in a vehicle fleet where lap-sash seatbelts in rear seats were rare. Historically, their use has been relatively rare but recently their use has become more common [9]. This is despite the fact that fewer vehicles are fitted with lap-only belts. Guidelines for the usage of CSHs provided by different child safety advocates around Australia and New Zealand vary, and despite concerns regarding the potential for serious misuse consequences there is little evidence on which to base CSH ‘best practice’ guidelines. This study uses a series of simulated frontal impacts to examine the protection provided by CSHs when used correctly and when misused; and when used alone or with booster seats. The results demonstrate that a correctly used CSH performs no better than a lap-sash seatbelt, and that there is a substantial reduction in protection when a CSH is misused. A recent NSW observation study has found CSH misuse is extremely common. Based on the test results, and those from the observation study, we propose a set of ‘best practice’ guidelines for CSH usage. CSHs should only be used with a booster seat incorporating an anti-submarining feature in a seating position fitted with a lap-only belt and retrofitting of a lap-sash seatbelt is not an option.

Keywords

Child Safety Harness, Best Practice, Crash test, Booster seat, Misuse

Introduction

Child safety harnesses have been covered by the Australian Standard for child restraints since its introduction in 1970. The most common child safety harness design attaches to the vehicle via a top tether arrangement and has two loops at the bottom of each of the harness or shoulder straps through which the lap portion of the seatbelt is threaded as shown in Figure 1a. Based on the mass range listed for this type of restraint currently in AS/NZS 1754; 2004 [1], these restraints are designated as being suitable for children weighing from 14kg – 32 kg.

The initial appeal of child safety harness systems was that they provided some means for upper torso restraint in vehicles at a time when lap-sash seatbelts in rear seats were rare. Since the introduction of mandatory lap-sash seatbelts in the outboard positions of rear seats in Australia, their primary use has been intended to be used in conjunction with booster seats in centre rear positions fitted with lap-only belts (as a booster seat should be used in combination with lower and upper torso restraints). However they can be, and are, used alone (see Figure 1b). In recent times the use of harnesses instead of lap-sash belts has become more common. This is largely due to a perception that the harness system provides superior restraint than the lap-sash seatbelt for a young child, even when used with a booster seat, despite the fact that since the 1970’s, there have been concerns regarding the effects of over-tightening of the harness shoulder straps, a common occurrence. Over-tightening of the shoulder straps leads to the lap portion of the belt systems being pulled up the child’s torso possibly allowing the child’s pelvis to move forwards, and the torso to slip under the lap portion of the belt [2]. This is an event known as ‘submarining’.
Figure 1 A surrogate 6 year old child using a child safety harness with a booster seat (left) and without a booster seat (right).

Current Child Safety Harness Guidelines

Guidelines for the usage of child safety harnesses provided by different child safety advocates around Australia and New Zealand vary, and despite concerns regarding the potential for serious misuse consequences there is little evidence on which to base child safety harness ‘best practice’ guidelines. These guidelines are available in the forms of brochures or online resources at road safety advocates’ websites. Examples of the advice given regarding the use of CSH from various road safety advocates include:

- Harnesses are suitable for children weighing 14 – 32 kg, and can be used in conjunction with booster seats until a child weighs 26 kg and on their own after that [3, 4, 5, 6, and 7].
- The harness must be correctly installed in your vehicle and adjusted properly to fit your child [3, 4, 5, 6 and 7].
- It is recommended that the child restraint harness be placed in either the centre or the kerbside of the back seat. If using a harness (only for children over 26 kg), the child should be positioned in the centre of the back seat [8].
- They are portable and may be used when travelling in a taxi or when transporting extra children when you don’t have other restraints [3, 5].

How Child Safety Harnesses are being Used

Bilston et al [9] recently completed a cross-sectional observation study that provided population-referenced data on the restraints used and the extent and nature of incorrect restraint use among children aged 0-12 in NSW. In this study, 2.4% (weighted estimate) of children were using child safety harnesses. This is a substantial increase in usage from previous observational studies conducted by Paine and Vertsonis [10] where only 0.5% of children used child safety harnesses. Approximately 80% of those children using child safety harnesses were using them with booster seats, and 20% used them alone. Furthermore, 88% of those children were doing so in seating positions fitted with lap-sash seatbelts. The age of children using child safety harnesses ranged from 2 to 7 years, and the distribution is shown in Figure 2.
Misuse was extremely common among child safety harness users (85%). The lap portion of the belt was observed to be high across the abdomen in 70% of the users and ‘extremely high’ in 8% of the users. The types of misuse observed included the harness pulling the lap belt high, loose harnesses, loose lap belts, twisted webbing, non-use and incorrect-use of gated buckles/locking clips for converting lap sash belt to lap only belt and the use of harnesses with booster seats not compatible with the use of child safety harnesses.

In a study of 150 children aged 2-8 involved crashes conducted in NSW [11], 4 children (age range 3–8 years) were using child safety harnesses, and all 4 were injured. Two received only superficial injuries, and two received more serious injuries. Facial fractures were sustained by one child (7 years old) and injury to the small bowel occurred in the other child (3 years old). The injuries sustained by the 3 year old are indicative of loading of the abdomen and/or submarining. The more serious injuries occurred in more serious crashes, and there were no details available regarding the correctness of adjustment in any of the four cases.

Objective

The main objective of this study was to provide a research based guideline on how and when child safety harnesses should be used in order to best protect the wearer in the event of a crash. This was achieved by (1) comparing the protection offered by a correctly used child safety harness and a lap-sash seatbelt when used alone and in combination with booster seats; and (2) examining the reduction in protection offered by a child safety harness when used incorrectly compared to both a correctly used child safety harness and a lap-sash seatbelt.

Methods

A series of 12 simulated frontal impacts were conducted and the relative performance of the different restraint systems, lap-sash seatbelt, booster seat and child safety harness were compared. The test matrix is shown in Table 1.

All tests were conducted at the NSW Centre for Road Safety’s Crashlab laboratory. Crashlab’s Monterey rebound crash sled was used to conduct all simulated impacts. The sled is accelerated towards a concrete impact block by a system of bungee cords. The impact is controlled using a nitrogen filled programmer mounted on the front of the sled. A braking system is used to stop the sled after it has rebounded from the impact with the block.
Table 1. Test matrix

<table>
<thead>
<tr>
<th>No</th>
<th>Restraint Adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Test dummy sits alone with</td>
</tr>
<tr>
<td></td>
<td>Correct use of CSH</td>
</tr>
<tr>
<td>2</td>
<td>CSH with loose lap belt and tight harness</td>
</tr>
<tr>
<td>3</td>
<td>CSH with loose lap belt and loose harness</td>
</tr>
<tr>
<td>4</td>
<td>Lap-sash seatbelt</td>
</tr>
<tr>
<td>5</td>
<td>Test dummy sits on a standard booster seat</td>
</tr>
<tr>
<td></td>
<td>Correct use of CSH</td>
</tr>
<tr>
<td>6</td>
<td>CSH with loose lap belt and tight harness</td>
</tr>
<tr>
<td>7</td>
<td>CSH with loose lap belt and loose harness</td>
</tr>
<tr>
<td>8</td>
<td>Lap-sash seatbelt</td>
</tr>
<tr>
<td>9</td>
<td>Test dummy sits on an ASC booster seat</td>
</tr>
<tr>
<td></td>
<td>Correct use of CSH</td>
</tr>
<tr>
<td>10</td>
<td>CSH with loose lap belt and tight harness</td>
</tr>
<tr>
<td>11</td>
<td>CSH with loose lap belt and loose harness</td>
</tr>
<tr>
<td>12</td>
<td>Lap-sash seatbelt</td>
</tr>
</tbody>
</table>

The same basic test set up was used in each test. A generic child restraint test seat (complying with the requirements of AS/NZS 3629.1: 2004) with standardised seatbelt geometry was mounted to the crash sled facing the concrete impact block. This test rig was calibrated to achieve the test severity required for frontal testing in AS 3629.1: 2004 (i.e. a velocity change of 49km/h and a peak deceleration of 27g).

The test dummy used was the Hybrid III (HIII) 6 year-old. This dummy was instrumented with the following accelerometers and transducers:

- Head acceleration: 3-axis accelerometers (Ax, Ay, Az),
- Upper neck forces and moments: 6 transducers (Fx, Fy, Fz, Mx, My, Mz),
- Chest acceleration: 3-axis accelerometers (Ax, Ay, Az),
- Chest deflection: chest deflection potentiometers (Fx),
- Pelvic acceleration: 3-axis accelerometers (Ax, Ay, Az).

Dummy motion was captured using three high speed cameras. One was stationary, mounted on the impact block to provide a frontal view. The other two cameras were mounted on board the test sled. Targets were positioned on the test dummy at the head centre of gravity and at the pivot point of the knee and on the test rig to allow for the measurement of head excursion and femur excursion. The head and femur excursions were measured relative to a vertical plane through the top edge of the test seat.

All instrumentation was installed and calibrated in accordance with the manufacturer’s specifications.

Restraints

The tests were conducted with dummy restrained in combinations of three different restraint types (seatbelt, booster seats and safety harness). The seatbelts used were lap-sash inertia reel retractable belts with 300mm webbing buckle. Two common booster seats were used; a standard belt-positioning booster (“standard booster seat”) and a booster seat incorporating an anti-submarining clip (ASC, see Figure 3) referred as “ASC booster seat”. As shown, the ASC works to hold down the lap portion of the seatbelt system. The child safety harness used was the most popular design of safety harness used in Australia (Safe-N-Sound child safety harness, Series No.117/2004). All restraints were attached to the test seat in accordance with the manufacturers’ instructions and the requirements of AS 3629.1. For correct use testing, the dummies were fitted to the restraints in accordance with the manufacturers’ instructions.
Child Safety Harness Misuse

Two common forms of child safety harness misuses were simulated in this test series see Figure 4.

Results

The most significant set of results for this study relates to the head and femur excursions. This excursion data are presented in Table 2. Femur excursion is related to the degree of submarining that occurred in each restraint system. Submarining occurs when the lap belt is allowed to move up into the abdomen of the dummy and the pelvis is allowed to slide forward. Differences in the degree of submarining are apparent in the overall motion of the dummy. Figure 5 demonstrates the results when the restraint systems were used alone at maximum femur excursion. Submarining was observed in all cases when the safety harnesses were used correctly and incorrectly (Figure 5a, b, and c). However, the extent was greater when it was misused with “loose lap belt” (Figure 5c). The magnitude of the submarining was so great, and it occurred in such a way that the upper chest cross strap made a direct contact with the dummy’s neck, see Figure 6. Submarining did not occur when the dummy used a lap-sash seatbelt (Figure 5d).

Table 2. Maximum head and femur excursions for each test configuration

<table>
<thead>
<tr>
<th>Test dummy sits alone with</th>
<th>Max Head Excursion (mm)</th>
<th>Max Femur Excursion (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct use of CSH</td>
<td>509</td>
<td>747</td>
</tr>
<tr>
<td>CSH with loose lap belt and tight harness</td>
<td>455</td>
<td>851</td>
</tr>
<tr>
<td>CSH with loose lap belt and loose harness</td>
<td>638</td>
<td>694</td>
</tr>
<tr>
<td>Lap-sash seatbelt</td>
<td>579</td>
<td>645</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test dummy sits on a standard booster seat</th>
<th>Max Head Excursion (mm)</th>
<th>Max Femur Excursion (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct use of CSH</td>
<td>572</td>
<td>783</td>
</tr>
<tr>
<td>CSH with loose lap belt and tight harness</td>
<td>530</td>
<td>935</td>
</tr>
<tr>
<td>CSH with loose lap belt and loose harness</td>
<td>680</td>
<td>785</td>
</tr>
<tr>
<td>Lap-sash seatbelt</td>
<td>648</td>
<td>743</td>
</tr>
</tbody>
</table>
Table 2. (continued)

<table>
<thead>
<tr>
<th>Test dummy sits on an ASC booster seat</th>
<th>Max Head Excursion (mm)</th>
<th>Max Femur Excursion (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct use of CSH</td>
<td>623</td>
<td>748</td>
</tr>
<tr>
<td>CSH with loose lap belt and tight harness</td>
<td>620</td>
<td>819</td>
</tr>
<tr>
<td>CSH with loose lap belt and loose harness</td>
<td>715</td>
<td>806</td>
</tr>
<tr>
<td>Lap-sash seatbelt</td>
<td>663</td>
<td>765</td>
</tr>
</tbody>
</table>

Dummy motions when the restraint systems were used with a standard booster seat and an ASC booster seat are presented in Figure 7 and Figure 8, respectively. Similar results were observed when the restraint systems were used alone and when used with a standard booster seat. The use of the standard booster seat made no difference to the extent of submarining compared to without a booster seat (Figure 5c compared with Figure 6c). However, the use of the ASC booster seat prevented the test dummy from submarining, when the child safety harness was used correctly and in both forms of harness misuse (Figure 8a, b and c).

Figure 5. Maximum femur excursion (no booster seat)

(a) Correctly fitted CSH only
(b) Incorrectly fitted CSH only (both loose)
(c) Incorrectly fitted CSH (lap belt loose) with resultant submarining
(d) Lap-sash seatbelt (no CSH)
Figure 6. The ‘loose belt’ test allowed direct contact between the dummy’s neck and the upper chest cross strap of the CSH (see arrow)

(a) Standard booster seat and correctly fitted CSH
(b) Standard booster seat and incorrectly fitted CSH (both loose)
(c) Standard booster seat and incorrectly fitted CSH (lap belt loose)
(d) Standard booster seat and lap-sash seatbelt

Figure 7. Maximum femur excursion of the dummy in a standard booster seat
Conclusion and Discussion

Based on the results from this study, it is clear that in frontal impact at least, child safety harness systems provide no better protection than lap-sash seatbelt systems, either with a booster seat or alone. When child safety harness systems are misused the level of protection provided is seriously degraded. Given the high frequency of child safety harness system misuse seen in field observation studies, and the fact that even when correctly used these systems provide no benefit over a lap-sash seatbelt, it seems likely that the risks of injury outweigh any likely benefit of a child safety harness system over a lap-sash system.

Submarining carries an increased risk of injury to the abdomen and to the spine. The tendency for the lap belt in a child safety harness to be positioned over the abdomen is very high, even when the child safety harness is correctly used, and consequently the harness system carries an increased risk compared to a lap-sash seatbelt.

The head excursions in the correctly used child safety harness systems were less than in the lap-sash seatbelt with and without booster seats. The lap-sash seatbelt allows between 40–76 mm extra head excursion. There was about 579 mm of head excursion in lap-sash seatbelt system when no booster seat was used, and about 663 mm when a booster seat was used. The head excursion was measured from a vertical plane through the top front edge of the test seat which is similar to the method used in the US Federal Motor Vehicle Safety Standard (FMVSS) No. 213 [13]. Nevertheless, the head excursions measured are well below the 813 mm limit placed on head excursion currently specified for belt-positioning booster seats by FMVSS 213 [13]. Most of these lower head excursions are associated with the submarining that occurred in child safety harness use. It is also believed that the lower head excursion in child safety harness is attributed the stiffer webbing system in child safety harness than in lap-sash seatbelt. The seatbelt system allows the belt to roll out for a certain period of time before the locking mechanism is activated. However, the lap-sash seatbelt clearly provided better pelvic restraint than the child safety harness unless an anti-submarining feature was used (and then the level of pelvic restraint was similar). The relatively small increase in head excursion in the lap-sash system is offset by the reduced stiffness of the restraint system and the superior pelvic restraint.
Limitations of this study include that this study evaluated child safety harnesses only in frontal impacts. This test configuration was chosen because the primary potential benefit of child safety harnesses was thought to be the additional upper torso restraint in frontal impacts. This is also the impact condition most likely to result in submarining, and thus frontal impacts are the most appropriate test condition to compare the potential benefits against risks. Differences between child safety harnesses and lap-sash seatbelts in side, oblique, and rear impacts have not been evaluated in this study. It is also possible that the magnitude of the relative risk of submarining may vary with impact speed, and this was also not evaluated in this study. In addition, the Hybrid III 6 year old dummy was used as a child surrogate in this study, as it represents a child in the mid-to-upper end of the size range for booster seats. This dummy is also thought to be a conservative model for submarining propensity due to the moulded pelvis design. The latter suggests that the results showing submarining in child safety harnesses are conservative. However, motion may differ with the size of the child and the fit of the restraint.

In the past, child safety harnesses were encouraged primarily for use in conjunction with booster seats in seating positions fitted with lap-only belts. However, since the introduction of mandatory lap-sash seatbelts in the outboard positions of rear seats in Australia, lap-only belt seating positions are becoming less common. This work clearly demonstrates that there is no need to use child safety harnesses in seating positions fitted with lap-sash seatbelts. Furthermore, if child safety harnesses are allowed to be used it is imperative that public are advised of the danger of ‘over-tightening’ the harness and/or not tightening the lap belt. In addition, the standard for child restraints should be amended so that all child safety harnesses are equipped with an anti-submarining feature or some other means of keeping the lap belt low.

Although the Australian and New Zealand Standard for child restraints requires a warning that states, “the lap portion of the seatbelt must be adjusted firmly first, and then the harness, so that the belt is not lifted off the child’s lap when the harness is adjusted” to be permanently printed on the harness and its instruction manual. Unfortunately, these warnings seem inadequate on its own as the field study suggests that misuses are happening even when the warnings are provided. Therefore, a communication strategy is required to tackle this problem. This includes; provisions of information regarding correct and appropriate use in languages other than English on packaging and within instruction booklets, one page pictorial set up and usage guides, better clarity in diagrams such that the information contained with diagrams on packaging, labels and in instructions books conveys all necessary information with no need to read any additional text, placement of labels on restraints in the vicinity of the task to which they refer, and colour coding of instructions, labels and seat belt routing.

The 7th Amendment Package of the Australian Road Rules requires children between the age of four to seven years old to use a booster seat, unless they cannot safely be restrained therein (i.e. too tall or heavy). Therefore this rule does not allow children in that age group to use only child safety harness alone. Child safety harnesses can only be used by children up to the age of 7 years old in conjunction with a booster seat. For children 7 years or older and less than 10 years (approximately 32 kg), child safety harnesses will continue to be available for use with booster seats or alone. Based on pelvic restraint, head excursion and abdominal injury potential, results from this study suggest that in frontal impact there is no benefit of using a child safety harness over a lap-sash belt for children using booster seats, and this practice should be discouraged unless the booster seats have anti-submarining features.

Proposed Guidelines

- Child safety harnesses should only be used in seating positions where a lap-sash seatbelt is not available.
- Retrofitting of lap-sash seat belts to seating positions fitted with lap-only seats should be encouraged.

**Children aged between 4 and 7 years:**
- Must not use child safety harness alone (without booster seat).
- Should use a booster seat with lap-sash seatbelt.
- Child safety harnesses are only necessary in positions with lap-only seatbelts and must be used with a booster seat preferably with anti-submarining features.

**Children aged over 7 years:**
- Children over 7 years of age who are too large for a booster seat should use lap-sash seatbelt instead of child safety harness.
- Child safety harnesses should be used for children over 7 years old as the last resort in seating positions where there is only a lap-only seatbelt available.

References