Misuse of Forward and Rearward Facing Child Restraints in Child Passenger Fatalities in New South Wales, Australia and the Relative Performance in Frontal Crash Testing.

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I. INTRODUCTION

Occupant restraint systems such as seat belts are the most effective way to reduce the risk of injury in a motor vehicle crash [1,2]. However, the standard three-point lap-sash seat belt system is not appropriate for all occupant sizes. For children, the maximum benefit is provided by a restraint system that is specifically designed for the size of the child (an appropriate restraint) when it is used exactly as intended by the manufacturer (used correctly). Inappropriate and incorrect restraint use is associated with more serious injuries in the event of a crash and is unfortunately common among hospital admitted children following a crash [3] as well as in the general population of children travelling in cars [4].

The most appropriate restraint for the child size progresses as they grow from a rearward-facing child restraint system in infancy through to a forward-facing child restraint system with an inbuilt harness, a booster seat and then to the adult seat belt once they reach a size to achieve good protection from adult restraint systems. Legislation in New South Wales (NSW), Australia, requires children up to at least 6 months of age to be secured in a rearward facing restraint, children aged from 6 months to 4 years secured in either a rearward or forward facing restraint with an inbuilt harness and children aged from 4 to 7 years secured in a forward facing restraint with inbuilt harness or a booster seat [5]. Best practice recommendations in Australia are that children should use a rearward facing restraint until they are too tall for it, a forward facing restraint until they outgrow this type of restraint and a booster seat until they achieve good seat belt fit in an adult seat belt. These best practice recommendations considerably extend the minimum duration required by legislation that small children travel in rearward facing restraints, with restraints available on the Australian market suitable for children from birth to approximately 30 months of age. In other countries the minimum legislated age children can move to forward facing restraints varies but is generally beyond the minimum 6 month required under Australian law, however to date there has not been enough evidence of harm to young children in forward facing restraints in Australia to warrant legislative changes.

Incorrect use of a child restraint system may relate to errors in how the restraint is secured to vehicle (installation) and/or how the restraint is used by a child (securing). Not all errors have the same impact on the protection provided by child restraints in a crash, and errors are commonly categorised as minor if they have minimal impact and serious if they result in a tangible degradation of crash protection. The most common serious installation errors observed in Australian observation studies include seat belt slack > 25 mm, incorrect seat belt routing, and seat belt not engaged while the most common serious securing errors include harness very twisted, very loose harness and partial use of the harness. These studies have also found that installation errors were equally as common in rearward and forward facing restraints while securing problems were more common in forward facing restraints compared to rearward facing restraints [6].

Incorrect use of a child restraint has been shown to be associated with more serious crash injury [3] and multiple minor errors have been shown to have a similar negative effect on forward facing child restraint performance as serious errors [7]. While there is evidence of difference in incidence of different types of errors between rearward and forward facing restraints, the effect of different errors on forward and rearward facing child restraint performance and real world injury outcomes has rarely been compared directly. One recent laboratory study found that rearward facing restraints appear to be less affected by errors than forward facing restraints using a test dummy representative of a three-year-old child [8]. However, there has been little study of this issue using real world data. Furthermore, given the current minimum age for transition between rearward and forward facing restraints in Australia, the influence of errors on the performance of rearward and forward

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facing restraints suitable for this size of child remains an important issue. The question about appropriate age for this transition is also important for low-middle income countries introducing new child restraint legislation.

One aim of this study is to examine the incidence and type of misuse in forward and rearward facing child restraint systems within a collection of fatally injured child passengers in NSW, Australia, and their contribution to the injuries sustained. We further aimed to compare the effect of misuse on the dynamic performance of forward and rearward facing child restraint systems for a one-year-old child.

II. METHODS

Misuse in Child Passenger Deaths in NSW, Australia

In NSW, the child death review team (CDRT) is convened by the NSW Ombudsman to investigate and maintain a register of child deaths. This register contains data from public organisations such as the police, ambulance and hospital records who are legally required to provide the CDRT with complete access to their records. Fatal motor vehicle crashes in NSW are almost always examined in-depth by crash investigators and forensic police officers, hence this detailed crash data is available to the CDRT in the event of a child passenger fatality. For this study, non-identifiable data were collected from the CDRT register for all NSW child passenger (0-12 years of age) deaths in passenger cars for a ten-year period between 2007 and 2016. These data included crash, injury and restraint data primarily taken from photographs and reports of in-depth at-scene crash investigation officers, witness reports and medical reports including autopsy where available. To minimise the risk of identifying specific crashes or individuals, and in-line with our approved ethical protocols we are able to only report group data and when group sizes are three or less, these are reported as three or fewer children.

The cases were examined for evidence confirming incorrect restraint use of rearward and forward facing child restraint systems based on on-scene reports (by police, ambulance officers and witnesses) within the case file and corroborated by post-crash photographs and evidence of external injury. Examples include the following: Errors in top tether use, i.e., anchored to the wrong point, very twisted or loose; Non-use of top tether; Non-use or partial use of the internal harness; Poor adjustment of the harness height; and Seat belt anchoring the restraint to the seat being unbuckled.

The mechanism and source of the fatal injury or injuries were determined in each case through assessment of the injury data and crash factors. Based on this information, the primary contributor to death was determined as either related to the restraint misuse or to intrusion into the occupant space, ejection of the child from the vehicle, a post-crash fire.

Dynamic Frontal Crash Testing with Misuse

Frontal crash tests were performed on a deceleration sled at the Transurban Road Safety Centre at NeuRA at 56 km/h (32 g). A test bench constructed according to Australian and New Zealand standard AS/NZS 3629.1:2013 was affixed to the sled table upon which a Infasecure CS8113 Quattro Element A2/B convertible child restraint system was placed for testing. This child restraint is intended to accommodate up to a large 12-month old child in rearward facing mode and up to a large four-year-old in forward facing mode. A Q1 anthropometric test device (ATD) was used for testing. Three accelerometers recorded the head response at the head centre of gravity, three accelerometers in the chest recorded the chest response and a six-axis upper neck load cell recorded the neck forces and moments. Signals were filtered according to SAE J211 with accelerometer and force data cut-off frequency of 1650 Hz (CFC 1000) and moment data cut-off frequency of 1000 Hz (CFC 600). Two high-speed cameras recorded the deceleration event from a lateral and overhead view. A custom MATLAB script was used to calculate the Head Injury Criterion (HIC) from the ATD head response.

The convertible child restraint was tested in both forward and rearward facing modes as intended by the manufacturer for a baseline test condition. Subsequent testing was carried out in both forward and rearward facing modes with the addition of the following types of misuse: 75 mm seat belt slack, very loose harness, partial use of the harness, 50 mm top tether slack, three minor errors (twist in harness, loose harness, twist in seat belt). The very loose harness condition was repeatedly achieved by placing two 23 mm thick spacers behind the back of the ATD and tightening the harness to the baseline equivalent tightness, then unbuckling the harness to remove the spacers and refastening the harness without further adjustment. For the loose harness condition, the same procedure was followed with one 23 mm thick spacer. The partial use of the harness condition involved placing only one shoulder of the ATD within the harness as pictured in Figure 1. Each test condition was tested twice and the results averaged.

Fig. 1. Partial use of harness condition in rearward (left) and forward (right) facing child restraint modes.

III. INITIAL FINDINGS

Misuse in Child Passenger Deaths in NSW, Australia

Over the 10-year period 2007-2016 there were 64 fatally injured children travelling in passenger cars in NSW. There were three or fewer children using a rearward facing child restraint system and 12 were using a forward facing child restraint system. There were no cases of misuse of rearward facing child restraint systems while two-thirds of forward facing child restraints (8) were used incorrectly. Of these eight cases of misuse in forward facing restraints, multiple errors were present in three or fewer.

The primary contributor to death was misuse in four cases of forward facing child restraint use and none for rearward facing restraint. Of these deaths related to misuse, the most common type of misuse was partial use of the harness, harness straps too high, twisted harness straps, loose and twisted top tether and no top tether. In all cases of multiple errors, the misuse was the primary contributor to death.

Dynamic Frontal Crash Testing with Misuse

The comparative performance of the convertible restraint in rearward and forward facing modes in terms of HIC15 is shown in Figure 2. The proportional change in HIC36 due to each misuse condition in comparison to the baseline is shown in Figure 3. A similar trend was observed in chest acceleration. Errors in data acquisition software setup resulted in loss of some data from neck load cells, preventing a complete comparison.

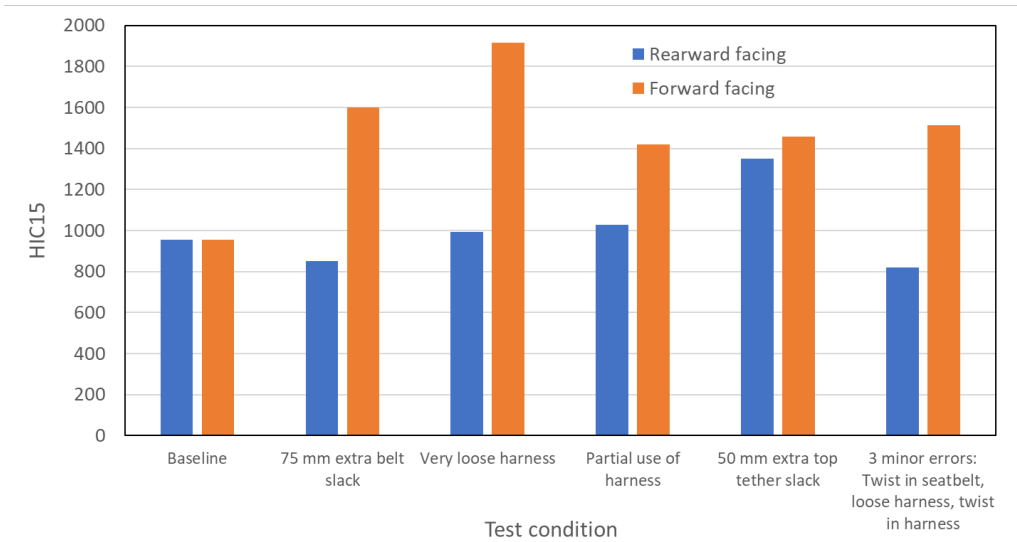

Fig. 2. Comparative head response in rearward and forward facing modes in each test condition.

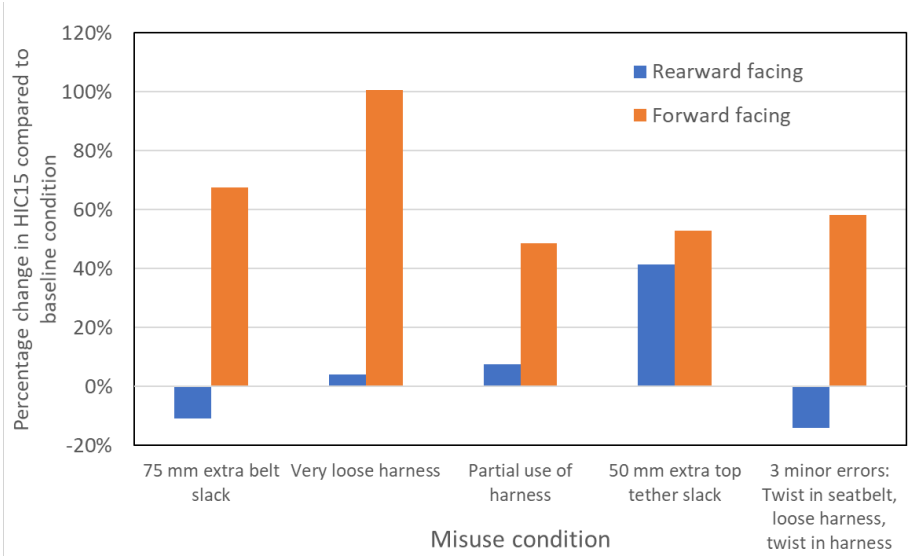

Fig. 3. Proportional change in HIC15 in each misuse condition compared to the baseline condition.

IV. DISCUSSION

Examples of child restraint misuse were observed among fatal child occupant crashes in NSW, Australia. This misuse occurred exclusively in forward facing child restraints while no misuse was observed in rearward facing restraints. A previous statewide estimate found that 50% of children were incorrectly restrained and 38% in a serious manner [6]. Although only a small sample, the proportion of incorrect use among children restrained in forward facing restraints (67%) is similarly large in this sample of child passenger fatalities. Harness and top tether misuse were the most common errors seen among the fatally injured cases, in common with a previous population observation [6]. Countermeasures such as ISOFIX anchorages and fitting stations may help address installation errors but strategies to address *use* errors, such as with the inbuilt harness, are also needed.

The dynamic frontal sled test results indicate that the particular restraint tested provides a lower risk of injury to a one-year-old size child in rearward facing mode compared to forward facing mode when errors are introduced. Top tether misuse had the largest negative effect on head injury risk in rearward facing mode while a very loose harness provided the highest head injury risk when forward facing. Further testing with more types of restraints is needed to determine whether these trends are specific to the restraint tested. Furthermore, containing the head within a *safe* occupant space, and understanding differences in neck loading are also important and these will be further explored in ongoing work. In the absence of means to reduce occurrence of securing errors, our preliminary results support keeping children rearward facing as long as possible.

V. REFERENCES

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