Inappropriate restraint use by child occupants - injury implications and factors in inappropriate use

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Abstract

Several recent studies in Australia have demonstrated that inappropriate use of restraints by child occupants is widespread, particularly in children aged 3-8. Most commonly, this takes the form of premature graduation to booster seats and adult seatbelts. This paper will give an overview of the problem, the injury implications, and the factors associated with inappropriate restraint use, using data drawn from a telephone survey of restraint use, other recent Australian studies of restraint use, and our crash investigation and child injury studies. Key factors emerging from these studies indicate that parental education level, knowledge of good restraint practices, family size, and trip type all influence the likelihood of children being appropriately restrained. Inappropriate restraint use is associated with an increased risk of serious injuries in crashes. The implications of these findings for the effectiveness of potential countermeasures such as legislation, education, restraint loans and subsidies will be discussed. Finally, other aspects of our research indicating the need for dedicated child restraint systems for larger children will be summarised and discussed in terms of proposed changes to the Australian Child Restraint Standard.

Introduction

Inappropriate restraint use by child occupants is defined as the use of a restraint by a child who is not suitable for that restraint on the basis of their size. Examples include the use of adult belts by young children; the use of booster seats by toddlers who are more appropriately restrained in forward-facing child restraints; and, the use of forward-facing restraints by infants who are less than 6 months of age. Inappropriate use is associated with an increased risk of injury for child occupants (Valent et al, 2002; Durbin et al, 2003; Arbogast et al, 2004; Brown et al, 2006; Brown et al, 2006 (a); Elliot et al, 2006)

International studies suggest that inappropriate restraint use by child occupants is widespread, and that the most common form is the use of adult seatbelts by young children (typically those aged 2-8 years), for whom the seat belt geometry is poor (Winston et al, 1999; Eby et al, 2001; Winston et al, 2003; Simpson et al, 2003; Ebel et al, 2003; Eby et al, 2005; Simpson et al, 2006).

Problems associated with a mismatch between seat and belt geometry and child size are likely to be responsible for a significant proportion of the increased injury risk seen when young children use seat belts rather than a restraint type more suitable for their size. The mismatch between lap belt geometry, seat cushion length and the anthropometric and anatomical attributes of the child's lower torso, pelvis and legs results in poor positioning of the lap belt. Specifically the lap portion of the belt is more likely to ride up over the soft abdomen rather than remaining low across the bony iliac crests of the pelvis. This underlies an observed increase in the frequency of abdominal injuries in children prematurely using adult belts (Lutz et al, 2003; Nance et al, 2004)

The mismatch between sash belt anchorage location and the seated height of the child often results in the sash portion of the belt crossing the neck rather than being located across the middle of the shoulder. This may be associated with an increased risk of injury but possibly more importantly it is also likely to increase discomfort which might increase the chances of sash misuse.

Injuries associated with inappropriate use have been seen in a recent Australian study of children in crashes (Brown et al, 2005) That study also noted that sub-optimal restraint use

by children (defined as inappropriate use, incorrect use or both) was the norm. A number of recent Australian studies have attempted to assess the patterns of restraint use by Australian children in different states (Bilston et al, 2006; Edwards et al, 2006; Charlton et al, 2006). These have confirmed that inappropriate restraint use is common.

This paper reviews the most recent Australian findings on restraint use by child occupants, reports preliminary findings from a study into the factors that are associated with inappropriate restraint use, and discusses the injury mechanisms and implications of inappropriate restraint use. A companion paper addresses restraint misuse.

Methods

Child restraint usage studies

Recent studies performed in Australia estimating restraint use patterns by child occupants under the age of ten were reviewed. These include a study of children aged 4 – 11 years in Victoria and NSW using a mail-back survey design (Charlton et al 2006); an observational study conducted in metropolitan South Australia (Edwards et al, 2006); and, a Queensland based observational survey of restraints using a convenience sample.

Figures on inappropriate restraint use in these studies were extracted. These were then presented and compared to data collected using a random telephone survey in NSW of parents or carers of children aged 0-10 years conducted by our group, and rates of inappropriate use seen in our field study of children in crashes.

The telephone survey used a structured questionnaire, and collected data on up to two children under ten in a family. Data collected included restraints used, child's age, height, weight, situations when restraint use might change, parental knowledge of restraint safety, including recommended transition points between restraint types, knowledge of and opinions about laws governing child restraint and seat belt use, their confidence in their knowledge about restraining their child safely, the parent's own restraint use, and sample demographics. Restraint use was then assessed for appropriateness, based on height and weight data (when available) and age (if height and weight was not available). Relationships between restraint appropriateness and the other data were assessed. Further details of this study can be found in Bilston et al (2006).

Real world crashes

The injury implications of inappropriate restraint use were examined by drawing data from a recent study of children aged 2-8 who had attended a tertiary paediatric trauma hospital following a motor vehicle crash in which they were an occupant. This study has been reported in more detail elsewhere (Brown et al, 2005, 2006, 2006(a), 2006 (b)). In brief, data on injuries sustained was extracted from the medical records. Restraint use was determined either from an in-depth crash investigation (in a subset of 43 cases) or from reported data in the medical record (remaining 99 cases). The ambulance sheet, on which ambulance officers note the type of restraint used, and reported restraint use in the medical record were the data sources in the latter cases.

Crash Reconstructions

For a small sample of crashes, in which inappropriate restraint use occurred, and sufficient details of the crash were available from the in-depth crash investigation, a crash reconstruction was performed. Crashes were reconstructed on a small custom-designed crash sled. The vehicle interior was reproduced on the sled, and a crash dummy most similar to the occupant was used to simulate the crash. Crashes were simulated as they were thought to have occurred (i.e. with inappropriate restraint use) and also with more appropriate restraint use, to assess potential differences in occupant kinematics and dynamics between the different restraint scenarios. Details of the methodology are reported in more detail elsewhere (Bilston et al, 2005; Brown et al, 2006 (b); Bilston et al, 2007)

Results

Rates of inappropriate restraint use

Charlton et al (2006), in Victoria and NSW, found that booster seat use dropped from nearly 70% in four-year olds to 15% in 7 and 8 year olds. This approximates the rate of inappropriate use, since most of these children would likely be most appropriately restrained in a booster seat. Edwards et al (2006), in the South Australian study, found that inappropriate restraint use (as defined by weight) was less than 20% for children aged under 2 years, rising to 62-68% for children aged 6 years, with an overall value of 28-36%. The Queensland study found that 56% of children aged 1-3 years were using “very appropriate” restraints, and 25% of 4-7 year olds were using “very appropriate” restraints. They also note that a further 23% of 1-3 year olds and 29% of 4-7 year olds were using restraints that were “somewhat appropriate”. Results from our NSW random telephone survey found that inappropriate use for children under 1 year of age was uncommon (<10%), but began to rise from 2 years of age (37%) to 95% by 8 years of age. Of note was a jump in inappropriate restraint use at approximately 5-6 years of age, mostly as a result of children ceasing to use booster seats. All of these studies have similar reported rates of inappropriate restraint use, however they are somewhat lower than that seen in a sample of crash-involved child occupants for 2-4 year olds, but are similar for 5-8 year olds (Brown et al, 2006). This may reflect an over-representation of inappropriately restrained 2-4 year olds in the crash sample.

Premature graduation into booster seats was noted among the crash involved sample. Data collected through the random telephone survey also demonstrated that for children younger than 4 years, there was a much greater proportion of children using booster seats (34%) than there were using adult belts (4%). For children over 4, suboptimal restraint consisted entirely of adult belt use. Review of the data collected in South Australia reveals a similar trend. Data from the other studies were not relevant to this issue.

Factors associated with inappropriate restraint use

Several of the above studies have also attempted to examine factors that are associated with inappropriate restraint use.

Occasions for non-use of child restraints. Trip type was examined by the RACQ study, in which 57% of parents reported that there were occasions when they did not use a child restraint, with the most common being on short trips or when a restraint was not available (e.g. in a friend’s car or taxi). Similar factors were noted in Charlton et al’s study of booster-age children (2006), with 42% of children not using boosters in someone else’s vehicle and 24% not using boosters on short trips. Edwards et al (2006) also investigated

this issue, and found that 40% of parents reported occasions when a restraint was not used, with an emergency or when travelling in a friend's car being the most commonly reported occasions. Similar factors for variations in restraint practice were found in our data. Our analysis also revealed that children were less likely to be appropriately restrained when there were more children in the car, and that variation in restraint use practices was related to parental characteristics such as risk perception, willingness to negotiate on restraint use with the child and family size.

Predictors of inappropriate restraint use. Most investigators have noted that age is the strongest predictor of inappropriate restraint use, as shown above. Other factors that predict inappropriate restraint use are low parental education (NSW telephone survey), large family size (NSW telephone survey), poor knowledge of appropriate child restraint selection for child (NSW telephone survey, Charlton et al, 2006), the child attending school rather than preschool (Edwards et al, 2006), parental willingness to negotiate restraint use (NSW telephone survey), having another child using only a seat belt (Charlton et al, 2006) and parental age (Charlton et al, 2006).

Parental knowledge. The adequacy of parental knowledge of when to use particular restraint types, and when to transition from one restraint type to another was assessed in a number of these studies. Edwards et al (2006) rated parental knowledge of the CRS to booster transition as good (69%) or poor (31%), but the transition from booster to seat belts was less well understood, with only 32% having "good knowledge". Our NSW telephone survey study found that poor parental knowledge of the restraint transition age/weight recommendations was significantly associated with inappropriate restraint use in children aged 0-10. Both our study and the RACQ analysis found that approximately three quarters of parents felt that they knew enough about child restraints to restrain their children, despite the high rates of inappropriate use.

Injuries associated with inappropriate restraint use

In our field study, approximately 78% of children were inappropriately restrained. There was no moderate or severe (AIS 2+) injury among children who were both appropriately and correctly restrained. On the other hand, 28% of inappropriately restrained children sustained a moderate or severe (AIS 2+) injury. Analysis of the field study data as a group showed that inappropriately restrained children (after correcting for crash factors) had a substantially increased risk of moderate to serious injury compared to appropriately restrained children (OR 9.0, 95% CI 1.2–69.5). In particular, inappropriately restrained children were substantially more likely to sustain head, spinal, and abdominal injuries than appropriately restrained children (Brown et al, 2006(a)) The injury impact of inappropriate restraint use, in terms of overall injury severity, was not different for 2-4 year olds and 5-8 year olds. It is interesting to note that serious consequences of inappropriate use were seen more commonly in moderate to severe crashes.

Examination of specific cases showed that inappropriately restrained children sustained serious injuries to the head, cervical spine, lumbar spine, and abdomen. Two case examples are discussed further in the next section.

Preventability of injuries in inappropriate restraint use

Case 1. Inappropriate use of a seat belt by a 4 year old

In this crash, a four year old child was restrained by a lap/sash belt in a frontal crash with a change of velocity of approximately 40 km/hr. The child sustained an AIS 3 injury to the ileum, plus overlying abrasions to the abdomen consistent with seat belt contact. The injury was hypothesised to be due to poor location of the lap belt over the abdomen resulting in penetration of the belt into the abdomen and damage to the underlying tissue. The reconstruction investigated three restraint scenarios – seat belt alone, booster seat with lap/sash belt and forward-facing child restraint use. As the child was between 14 and 18kg, according to the Australian Standard AS/NZS 1754, either the booster seat or forward-facing restraint were appropriate. A Hybrid III 3 year old dummy was used, as this was the closest size dummy available. Stills from the high speed video are shown below in Figure 1. Note particularly the location of the lap part of the belt in the seat belt scenario, which penetrates into the abdomen of the dummy. This does not occur in either the child restraint or booster seat scenarios.

Figure 1. Position of child dummy at maximum excursion in three different restraint types. Note the position and more horizontal angle of the lap belt in the seat belt condition compared to the booster scenario, where the belt is more angled, and lower on the thighs.

Case 2. Inappropriate use of a seat belt by a 7 year old

In the real world crash, a small 7 year old was restrained by a lap/sash belt in a frontal crash with change of velocity of approximately 45km/hr. The child was thought to be sleeping at the time of the crash, with the head slumped towards the door, resulting in the seat belt wrapping around the neck. The child sustained a C2 fracture, without spinal cord injury, and swelling and extensive abrasions on the lateral part of the neck consistent with seat belt marks. There were also abrasions on the abdomen and chin. It was hypothesised that the neck injury occurred as a result of the belt restraining the lower neck while the head rotated sharply. The reconstruction was performed using a Hybrid III 6 year old dummy, as the closest match for the child's size. Three scenarios were simulated – with the dummy slumped sideways in an adult belt, with the dummy upright in an adult belt, and with the dummy in a booster seat. Initial postures are shown below in Figure 2. During the simulation, the dummy in the slumped position rotated more around the belt, while in the upright position, the dummy moved less laterally. There were difficulties in positioning the dummies in realistic postures due to the stiffness of the dummy.

Figure 2. Initial postures for Case 2. Note the position of the sash belt near the neck in the slumped scenario.

Figure 3. Kinematics of dummy in Case 2. Note the rotation of the dummy in the slumped case compared to the upright and booster scenarios.

Discussion

The current picture of restraint use by Australian children

Data from recent Australian child restraint usage studies described above indicate that inappropriate restraint use by child occupants is widespread among children after their 2nd birthday. The majority of this inappropriate use is "premature graduation" from one restraint type to another, particularly the use of adult belts among 5-8 year olds. Premature graduation to booster seats is also an issue of concern for 2 – 4 year olds. The direct implication of these findings, which appear to be robust across different states and methods of data collection, is that the message about what restraint children should be using is not reaching and being attended to by parents of toddlers and young children. This is supported by the fact that many parents do not appear to be well-informed about when their children should transition from one type of restraint to another apart from the transition to a forward-facing restraint (Edwards et al, 2006; Bilston et al, 2006). Analysis of the factors that predict inappropriate restraint use has shown that a variety of factors are involved. These include demographic factors, such as education level and family size; behavioural factors, such as parenting style and risk perception; and situational factors, such as trip type and travel in other people's vehicles. An important observation to highlight is among children in the 4-8 age group, there is a drop in booster seat use that coincides with commencing school. Edwards et al (2006) found that this was significant over and above the age effect. This may relate to increasing independence and/or willingness of parents to negotiate over restraint use in this age group.

Collectively this data indicates that current education based approaches alone have not been effective in achieving high rates of appropriate restraint use by children, particularly in the 2-8 age group.

Strategies to increase appropriate restraint use

Education. The results from the studies above have some implications for increasing the effectiveness of educational campaigns to increase appropriate use. First is the suggestion that parents of children older than two need to be provided with information on when to make the transition to a booster seat, and when to transition to a seat belt, as significant numbers of parents who do appropriately restrain their children currently possess this knowledge. The demographic data suggests that particular attention may need to be paid to parents with lower levels of education and larger families. Behavioural and parenting style factors such as a parent's willingness to negotiate restraint use with their child may result in premature transitions, therefore campaigns need to be designed with this in mind. Finally the data suggests it may be useful to directly target parents of children prior to starting school with information about the appropriate time to stop using a booster seat.

Legislation. The Australian Road Rules Maintenance Group has recently published draft new Road Rules which would require the use of a forward-facing child restraint until the 4th birthday, and a booster seat until the 7th birthday. An additional requirement in the proposed changes is to require rear seating position by children unless all rear seating positions are occupied by other children under 7. These draft changes are yet to be approved by the Australian Road Rules Maintenance Group and the Australian Transport Council and then enacted by each State. If supported by appropriate educational programs and enforcement, these changes have to potential to substantially increase the level of appropriate restraint use by children up to their 7th birthday by providing very clear messages about what restraints to use at what ages. Indeed, some parents in our recent telephone survey reported that they would find it easier to resist pressure from their child to stop using a booster seat if there was a legal requirement for them to continue doing so. The use of age rather than weight or height is supported by Edwards et al's (2006) findings, and also our telephone survey, in which many parents did not know (or provided inconsistent estimates) of their child's height and weight. In their current form, these changes will not require booster seat use for children 7 years of age or older, despite evidence that good seat belt fit is not achieved until 145cm in height (approximately 11.5 years of age). There may well be some "spillover" effect however, whereby children continue to use their restraints beyond the mandated age, as currently occurs with forward-facing restraints after 12 months. It is important to note that to achieve effective compliance with the proposed legislative changes, targeted educational campaigns (see previous section) will also be required. This has been demonstrated extensively with respect to seat belt laws – legislative change is not effective unless supported by carefully designed education programs. (Herbert et al, 1980) Enforcement is also an issue and this also needs consideration in respect of the proposed legislative changes.

Also important to note is that appropriate restraint use, by itself, is not enough to solve the problem of injuries to child occupants – incorrect use of restraints can also have deleterious effects (Brown et al, 2006). In particular, gross misuse of restraints (e.g. failure to buckle harnesses in forward-facing restraints, non-use of the sash belt etc) can substantially decrease restraint effectiveness. For the full potential benefits of mandatory appropriate restraint use to be realized, misuse must also be reduced. This is further discussed in a companion paper.

Injuries to inappropriately restrained children

The data from our real world crash study indicates that inappropriately restrained children are at a higher risk of serious injury in crashes, including serious head, spinal and abdominal injuries. This is consistent with findings from overseas (Valent et al, 2002; Durbin et al, 2003; Arbogast et al, 2004). Injury studies indicate that poor belt fit can result in loading of vulnerable parts of the body, particularly if the child is not in a "good" posture at the time of impact. The crash reconstructions indicated that appropriate restraint use may better control occupant motion, direct the restraint forces to regions of the body better able to withstand them, and thus reduce the risk of serious injury.

Conclusions

- Inappropriate restraint use by children is widespread among 2-8 year olds in Australia. This increases the risk of serious injuries to these children.
- Proposed changes to the Australian Road Rules will encourage more appropriate restraint use. These must be introduced with concomitant targeted education campaigns to maximise changes to restraint use behaviour.
- There is an existing body of data exploring the factors associated with inappropriate and appropriate restraint choices. These data should be used in the design of education campaigns to support legislative changes.
- In order to harness the full potential of these changes, we must reduce incorrect restraint use, as misuse can substantially reduce effectiveness of restraints used by children.

Acknowledgements

This research has been supported by funding from the Australian Research Council, the Motor Accidents Authority of New South Wales, the Roads and Traffic Authority of New South Wales and the National Health and Medical Research Council. We are grateful to RTA Crashlab and Holden for the loan of dummies for the crash reconstruction study and to our co-authors on the original studies that are referred to here.

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