A SAFE RIDE HEIGHT LINE FOR CHILD CAR OCCUPANTS

Michael Griffiths
Road Safety Solutions, NSW, Australia
Julie Brown
Prince of Wales Medical Research Institute, UNSW,
Michael Paine
Vehicle Design & Research, NSW, Australia
Australia
Paper No 09-0354

ABSTRACT

Studies of child occupant safety in cars in have consistently reported that one of the biggest problems with unsafe use of child restraints is premature graduation of children into restraint systems that the intended for older children.

In 2007 our team conducted a study to identify ways of ensuring that children travel in the safest restraint for their age and size. The outcome of the review was subsequently included in revisions to Australian road rules.

During the study we identified the potential for the concept of a 'safe ride height' line. That is, the child restraint systems, and vehicles in which they travel, could both be clearly marked with a 'safe ride height' line to be used to indicate whether a child was an appropriate size for the restraint.

The 'safe ride height' line could be integrated prospectively and retrospectively across the full width of the seat back of the vehicle. If a child's shoulders are below the line, the child is too small for an adult seatbelt.

In child restraints, the 'safe ride height' lines can be tailored for each type of restraint system. For example, in a forward facing child seat, there could be a lower 'safe ride height' line for a child who has just grown big enough, and an upper 'safe ride height' line for a child who now needs to graduate out of the restraint.

'Safe ride height' lines are included in the current draft for a revised Standard for child restraint systems in Australia.

What this paper offers that is new is the concept of a 'safe ride height' line that will provide an easy guide for carers as to the appropriate size restraint for a child and allow simple self evident enforcement of correct restraint usage rules.

INTRODUCTION

Premature graduation to booster seats and adult belts is widespread among child occupants in most developed countries [1-3], and is associated with an increased risk of injury [4-7]. Encouraging children to use the most appropriate restraint for their size is therefore a high priority in many jurisdictions.

The first step in achieving this is to clearly communicate to parents what restraint their child should be using and when their child should move to the next type of restraint. Graduation information is usually supplied to parents in terms of height and/or weight, and sometimes age. However, parents do not always know the height and/or weight of their children, particularly as their children move out of the infant and toddler stage. In a recent Australian telephone survey of parents with children aged 0-10 years, 16% reported being unsure of their child's weight, and 34% reported being unsure of their child's height (Brown & Bilston, unpublished data). Furthermore, without measuring heights and weights, parents often make inaccurate estimations [8]. This partly underlies the recent suggestion made by Anderson & Hutchinson [9] that restraint transition could be more easily complied with if parents and carers used age instead of weight and height.

Nevertheless, size, particularly seated height, is important in designing child restraint systems since:-

(i) there must be a good match between the restraint system and the size of child using the restraint, and
(ii) the quality of the transition from child restraint (i.e. booster) to adult seat belt requires a certain seated height and upper leg length to ensure adequate belt fit [10].

There are also some issues with weight in child restraint systems that use top tether straps as integral parts of the anchorage system as there is *theoretically* a need to stay within the design rule load requirements of tether anchorage points. Importantly however, in practice, there have been no reported failures of top tether anchorages in Australia, even in very severe real world frontal crashes up to 100km/hr in Australia since 1976. Full scale new vehicle crash barrier tests at up to 100km/h have also found no failures of top tethers or their anchorages (Griffiths & Wasiowycz, unpublished data).

The second step is the implementation of strategies to encourage parents/carers to always use the most appropriate forms of restraint for their child. This is achieved through widespread education campaigns and increasingly through mandating the appropriate size/age transitions using legislation. In countries or states with laws stipulating the use of specific types of restraint, the laws are written in terms of age or size, or a mix of both. However, it is well established that for legislation to be effective it must be accompanied by enforcement. Without realistic enforcement tools that are acceptable to enforcement officers, there is likely to be poor enforcement. Laws based on weight/height and age of child are difficult to check at the roadside. It is not realistic to expect police to carry weight scales and a tape measure, or for parents to carry a child's birth certificate with a photo ID.

Taking all of the above into account, we recently authored a discussion paper for the (Australian) National Transport Commission (NTC) reviewing child restraint legislation in Australia [11]. Previous Australian legislation required children up to 12 months of age to use a dedicated child restraint and beyond that age the legislation allowed the use of a dedicated child restraint or a seat belt. Clearly a one year old child should be in a dedicated child restraint with built-in harness rather then just an adult seat belt but the previous law has given some parents/carers the impression that a seat belt is acceptable.

The purpose of our review was to examine the possibility of extending the mandatory use of child restraints in Australia by addressing two primary issues: (i) if mandatory use of dedicated child restraints were to be extended, to what children should it be extended; and (ii) how should any legislation addressing appropriate use be written given age/size/weight issues outlined earlier. The discussion paper we prepared for the NTC formed the basis of a regulatory impact statement (RIS) [12] that initiated the formation of new Australian child restraint legislation based on child age. A copy of the legislation is included in Reference [11].

This paper presents a concept originating from that review aimed at improving the ease of communication of appropriate restraint transition sizes, and allowing for easier enforcement of legislation specifying appropriate restraint transitions. The benefits of the safe ride height concept were recognised in the RIS but were unable to be incorporated in this legislation as no vehicles were marked with these lines, and at the time the relevant Australian Federal authorities indicated they were unlikely to formulate a new Design Rule requiring ride height lines.

THE CONCEPT OF A 'SAFE RIDE HEIGHT' LINE FOR REAR SEAT OCCUPANTS

Anthropometric measurements are the best primary indicators of when good seat belt fit can be achieved [10]. Seated height and upper leg length in particular are important determinants for good seat belt fit, and these are likely to be related to overall stature, which is used by some jurisdictions to determine appropriate restraint usage. A difficulty is communicating the safety message associated which such measurements.

There are other common examples in the community where communicating a safety issue is achieved using 'safe height' indicators. For example, the Plimsoll line is a marking system at the waterline of a ship's hull to ensure the ship is not overloaded. "Safe height' indicators are also common at fairgrounds and amusement parks where a minimum height is needed to ensure safe retention of the child in the ride seat. These systems work because the regulatory 'height mark' is immediately available to both the users and enforcers. For fairgrounds, if you are not above the line, "you don't ride". The self evidence of the mark also assists parents and carers to explain to children why they are too small to ride.

We propose a similar approach for communicating the correct restraint transition size for child occupants. This would take the form of some marking on the vehicle seat trim that would indicate a minimum *seated shoulder height* for using a seat belt. The intention is that this would eventually replace the stature limit used in Europe and the USA for booster seats.

A recognised mark on the seat is clearly better than expecting parents to measure their children using a tape measure. It takes into account seat properties, such as the angle and a reclined seated height, child's seated position, and the downward compression of the seat base cushioning because of the weight of the child. It also removes the impractical need for enforcement officers to carry tape measures or other means of assessing height. Another advantage is that this allows children to see for themselves whether or not they fit the seatbelt. For example, this should assist the problem faced by parents of children who do not want to use child restraints because '*they are for babies*'.

THE ‘SAFE RIDE HEIGHT’ LINE LIMITS AND ASSESSMENT

The most commonly cited anthropometric transition point for child occupants moving into seat belts is a standing height of 145cm [10, 13-14]. This roughly equates to an 11.5 year old at the 50th percentile. In Europe, the recommended or legislated transition point varies from 135cm in some countries (equates approximately to the 50th percentile 9.5 year old) to 150cm in others (equates approximately to the 50th percentile 12.5 year old) [11]. These current recommendations are a useful starting point to determine what the ‘safe ride height’ line should be.

To include the ‘safe ride height’ line in a regulatory environment requires the availability of a measuring tool. There are two existing internationally accepted test dummies representing the 50th percentile 10 year olds. The overall length of these dummies falls within the 135cm to 150cm range and either dummy could be used as the reference tool, taking into account real child/test dummy seated posture differences like those described by Reed et al [18].

In our review we examined:-

- how to relate the seated ‘safe ride height’ line to anthropomorphic data on standing height, including the 1.35m to 1.50m guidelines

- whether the marked ‘safe ride height’ line should be at head height, eye height or shoulder height

Although generally overall height refers to the length between the floor and the crown of the head, accurately pinpointing the crown of a seated dummy’s head can be problematic (e.g. due to chin tilt). Similar problems exist for seated eye height. Seated shoulder height appeared to be better because the child’s shoulders are immediately adjacent to and normally resting on the seat back. Furthermore, seated shoulder height is a primary characteristic that is important in achieving good sash belt fit. Indeed, it could be argued that stature is a surrogate for this measurement.

Using United States data from 1997 [17] the correlation between seated shoulder height and stature among children aged four to twelve years is shown in Figure 1.

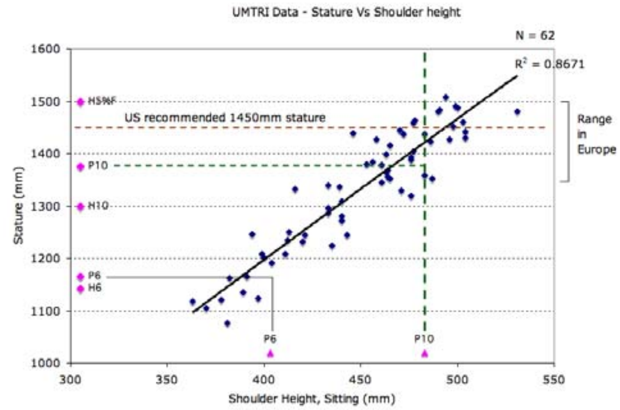

Figure 1: Shoulder height, stature, seat belt transition points and ATD anthropometry

Figure 1 also includes the relevant dimensions from a range of ATDs, where available. It is evident from this graph that the seated shoulder height of the TNO P10 ATD of 483mm (vertical dashed line) corresponds to the range of standing heights that have been suggested in Europe and the USA. That is, the P10 seated shoulder height is equivalent to a stature of about 1420mm in the US population (the actual stature of the P10 is 1376mm). This is slightly less than the 1450mm recommended by US authorities. It also spans most of the range of 1350mm to 1500mm standing height implemented in Europe.

At this point, we can not compare the seated shoulder height between the TNO P10 and the Hybrid III 10 year old, because we do not have that measurement for the Hybrid III available. However, the overall seated height of the two dummies is similar but exactly the same (72.5mm for the TNO P10 and 71.9 for the Hybrid III 10 year old) and we would expect the comparative seated shoulder height to be in the same ball park.

It is noted, that 1500mm stature is the same as that of the Hybrid III 5% adult female ATD. Basing the requirements on a seated shoulder height of 483mm, rather than 1500mm stature would exclude most small adult females from the booster rules, as intended.

Therefore we would propose the safe ride height line should be positioned close to a height of 483mm from the seat bite after allowing for some depression of the seat cushion because of the weight of the occupant. A possible alternative to using a dummy to specify this position, would be to use a simple test rig that simulates the seat cushion loading (i.e. mass and buttock shape) of the P10 dummy (i.e. something similar to a H-point machine).

As previously discussed, seated shoulder height is the primary measure for good sash belt fit. The main reason that standing height may have been used in booster rules to date is that it is perceived as more likely to be known by parents/carers (although subsequent surveys have shown that this is not the case) or that it is more readily linked to age through published growth chart data.

By introducing a 'safe ride height' line based on seated shoulder height in each vehicle seating position, the difficulties of determining child age or stature for enforcement of booster rules are eliminated.

Whilst other anthropometric measurements, such as seated eye height were considered by the authors, the seated shoulder height was clearly the most relevant and practical measurement to use for a 'safe ride height' line. For example any vehicle seat back not high enough to incorporate a shoulder height line would be unlikely to provide safe restraint for occupants whose shoulders were above the height of the seat back. Furthermore rear seat height is commonly below head and eye height (these areas being commonly protected by head restraints that occupy a small fraction of the width of the overall rear seat).

Figures 2, 3 and 4 demonstrate the 'safe ride height' line concept. The ride height line illustrated is indicative only and is 480mm above the seat bite. It is expected that using the TNO P10 ATD or some other means to measure height while depressing the cushion, would result in a slightly lower line.

Figure 2: 5 year old girl with a shoulder height clearly too small for the nominal safe ride height line.

Figure 3: 5 year old girl in booster and nominal safe ride height line

Figure 4: 13 year old boy with shoulder height greater than nominal safe ride height line.

OTHER BENEFITS

Other potentially significant benefits are that the 'safe ride height' line:-

- would be a compelling highly visible indicator of appropriate occupant height in rear seats

- as such, it would give vehicle manufacturers a stimulus to provide better sash belt geometry and provide an envelope in which they could optimise their sash belt fit.

CUSHION LENGTH, ANOTHER ISSUE

The 'safe ride height' line would effectively limit seated shoulder height for those using adult seat belts and give vehicle manufacturer's a more specific lower boundary to aim for when designing the sash geometry.

It would also address sash positioning problems associated with premature graduation to seat belts.

However, it would not have any influence on the current problem of the depth of the rear seat cushion.

Recent studies by Huang and Reed [15] and Bilston and Sagur [16] have demonstrated significant variability in rear seat cushion length and that current rear seat cushions are too deep for many occupants. Huang and Reed measured 56 vehicles in the North American fleet and found the rear seat cushion to be deeper than required for a 145cm child in all vehicles. Bilston and Sagur [16] in the 50 vehicles they measured from the Australian fleet, found all seat cushions were too deep for a child with upper leg length at the 50^{th} percentile until approximately 11.5 years, and half were too deep for a 15 year old at the 50^{th} percentile. With more attention being given to rear seat occupants it is expected that future seat cushion designs will cater for smaller occupants .

Whilst, in the authors' view, the benefits of a 'safe ride height' line are so significant that they should be quickly implemented, it is acknowledged that it would not resolve all of the problems with good seat belt fit in vehicles.

Better seat cushion length is an area that also needs attention.

EXTENDING THE CONCEPT TO CHILD RESTRAINT SYSTEMS

The 'safe ride height' line concept can easily be extended to dedicated child restraint systems and high back booster seats. The Australian/New Zealand child restraint Standards committee is currently considering a revised draft of the Standard that incorporates this concept. 'Safe ride height' lines are currently being incorporated as a more reliable way of identifying when children are too big or too small for the various classes of child restraints by using maximum and minimum 'safe ride height' lines. These match the upper and lower seated height for age limits of the various restraint types to correspond with the age based legislation being introduced into Australia (see reference 11).

PROPOSED METHOD FOR DETERMINING 'SAFE RIDE HEIGHT'

The following is suggested as one possible method for determining what the 'safe ride height' line should be in the seats of each vehicle.

1. Position the chosen anthropomorphic test device (e.g. TNO P10) in each seating position.
2. Position a "level" across both mid shoulder positions of the test dummy, so that one end of the level touches the seat back.
3. Record the positions on the seat back trim which is contacted by the level.
4. Position a tape or similar marker approximately 10 -20 mm wide (to allow for variability) to mark the 'safe ride height' line across the full width of the seat back of the seating position.

IMPLEMENTING THE CONCEPT

One way to implement the 'safe ride height' line concept would be to create an internationally harmonized vehicle regulation.

Alternatively, vehicle manufacturers could develop a voluntary set of guidelines to ensure uniformity across international markets.

Consumer strategies such as NCAP's could reward manufacturers who adopted this concept ahead of any mandatory requirements. In new vehicles it is envisioned the markings would be incorporated by manufacturers into the vehicle seat. For older vehicles there is the possibility of retro-fitting safe ride height indicators. In Australia this could be by the Government certified child restraint fitting stations. Elsewhere, organizations such as motoring service clubs could provide retro-fit services. However, since suitable child dummies are not readily available for this purpose it would be necessary for road safety authorities to arrange for each popular vehicle model to be assessed and safe ride height line locations determined. This information could then be disseminated for in-field use.

It would be feasible to develop a simple test rig that simulates the seat cushion loading (i.e. mass and buttock shape) of the P10 dummy and enables the safe ride height line to be established without the need for an expensive crash test dummy.

CONCLUDING REMARKS

In conclusion, the 'safe ride height' line concept:-

- provides a direct primary indicator of safe sash and shoulder height geometry tailored for each restraint system, in each seating position of a vehicle

- provides a simple, easy to understand, and easy to enforce tool to assist safer, more appropriate use of restraint systems

- is a minimal cost measure which could be quickly introduced for new and existing vehicles.

The content of this paper is the views of the authors only and does not reflect the views or policy of the Australian Government, Standards Australia or any other organisation.

ACKNOWLEDGEMENTS

The authors would like to acknowledge:-

- the Australian National Transport Commission (NTC) which funded the review which led to the identification of the 'safe ride height' line concept

- their co-authors in the NTC discussion paper Dr Robert Anderson and Dr Michael Henderson,

- others who provided comment particularly including Dr Lynne Bilston.

REFERENCES

1. Bilston LE, Finch C, Hatfield J, Brown J (2008) "Age-specific parental knowledge of restraint transitions influences appropriateness of child occupant restraint use" Injury Prevention 14(3):159-63

2. Ebel BE, Koespell TD, Bennet EE, Rivara FP. (2003) "Too small for a seatbelt: Predictors of booster seat use by child passengers" Pediatrics 111:e323-327

3. Willis C, Le Claire M, Visvikis C, Kirk A, Grant R "Overview report into the incorrect use of child restraints in selected countries" CHILD project Task 1.2 available from http://tinyurl.com/dxwo6v[accessed 25/02/09]

4. Durbin DR, Elliott MR, Winston FK, (2003) "Belt-positioning booster seats and reduction in risk of injury among children in vehicle crashes" JAMA 289(21):2835-2840

5. Du W, Hayen A, Bilston LE, Hatfield J, Finch C, Brown J, (2008) "The association between different restraint use and rear-seated child passenger fatalities: a matched cohort study", Arch Pediatr Adolesc Med, 162: 1085 – 1089

6. Brown J, McCaskill ME, Henderson M, Bilston LE (2006) "Serious injury is associated with suboptimal restraint use in child motor vehicle occupants" J Paediatrics & Child Health 42(6) 345-349

7. Elliott MR, Kallan MJ, Durbin DR, Winston Fk (2006) "Effectiveness of child safety seats vs seat belts in reducing risk for death in children in passenger vehicle crashes" Arch Pediatr Adolesc Med, 160(6):617-21

8. Huybrechts I, De Bacquer D, Van Trimpont I, De Backer G, de Henaw S (2006) "Validity of parentally reported weight and height for preschool-aged children in Belgium and its impact on classification into body mass index categories" Pediatrics 118:2109-2118

9. Anderson RWG, Hutchinson TP (2007) “The feasibility of age-based criteria for child restraint selection” 20th ESV Conference, Lyon France Paper No 07-0220 pp10

10. Klinich, K.D., Pritz, H.B., Beebe, M.S., Welty, K.E. (1994) “Survey of older children in automotive restraints” SAE paper 942222 Stapp Car Crash Conference

11. Paine M, Brown J, Griffiths M, Anderson R, Henderson M (2007) "Review of Australian Regulations for Child Restraint Systems", Discussion paper prepared for National Transport Commission, February 2007 (unpublished).

12. National Transport Commission (2007) "AUSTRALIAN ROAD RULES 7th AMENDMENT PACKAGE 2007 DRAFT REGULATORY IMPACT STATEMENT May 2007" available at: http://tinyurl.com/3y44lr

13. American Academy of Paediatrics (2005) "Car Safety Seats: A guide for families" at http://www.aap.org/family/carseatguide.htm

14. U.S. Department of Transportation, National Highway Traffic Safety Administration at: http://www-nrd.nhtsa.dot.gov

15. Huang, S. and Reed, M.P. (2006). "Comparison of child body dimensions with rear seat geometry". *SAE Transactions: Journal of Passenger Cars – Mechanical Systems,* 115.

16. Bilston L and Sagar N, “Geometry of rear seats and child restraints compared to child anthropometry, Stapp Car Crash Journal 51:175-198, 2007.

17. Reed MP, Ebert-Hamilton SM, Manary MA, Klinich KD, Schneider LW (2006) “Improved Positioning Procedures for 6yo and 10yo ATD’s Based on Child Occupant Postures. Stapp Car Crash Journal Vol 50:337-3888

18. Consumer Products Safety Division data used by Michael Paine (1997)