THE FEASIBILITY OF AGE-BASED CRITERIA FOR CHILD RESTRAINT SELECTION

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ABSTRACT

Surveys of automotive child restraint use in various countries have repeatedly shown that many parents do not select the correct type of restraint for the child and lack knowledge about correct restraint selection. Advice to parents is based on the dimensions of the child, usually weight, but such prescriptions may be difficult for parents to remember, and parents often do not know the weight of their children. The child's age might be preferable for promotion and regulation because parents know it. Using a dataset of the distribution of children's weights at one-month intervals of age, and assuming that all children change from one restraint device to another at a particular age, we demonstrate the trade-off between the number of children too large for the smaller device and the number too small for the larger device. This is used to suggest an optimum transition age. The regulatory jurisdictions of Australasia, Europe and the United States of America are compared. The analysis shows that in Australasia, where there are currently significant overlaps in the weight ranges of each type of restraint, recommendations to make restraint transitions at 6 months and 4 years of age would mean that about 10% of all children under the age of 8 would be in a restraint unsuited to their weight. Corresponding figures for the European and United States Standards are 6% and 16%. Instead of battling to get parents to use child's weight as the criterion for restraint selection, it might be better to promote exact ages as the transition criteria, and to write the Standards for child restraints on the basis that this will happen.

INTRODUCTION

Surveys of automotive child restraint use show that children often graduate from one type of restraint to the next at too young an age. This is so whether we are referring to different types of child restraints, to belt-positioning booster seats, or to adult belts (Apsler et al., 2003; Brown et al., 2005; Durbin et al., 2001; Ebel et al., 2003a; Simpson et al., 2002).

Interventions to increase correct restraint use often contain an education element designed to increase knowledge about criteria for restraint selection and use (e.g. Apsler et al., 2003), and the Association for the Advancement of Automotive Medicine sees education as an integral part of a strategy to improve the safety of children in automotive crashes (Durbin et al., 2003). Efforts to instil knowledge in parents can lead to increased rates of correct restraint use (Ebel et al., 2003b). However, in the present paper, we take an alternative approach. We will accept that parents often do not know either the weight of their child, or the weight range for which a given restraint is suitable. But they do know the age of their child. Therefore we ask how serious it would be – in terms of the number of children inappropriately restrained – if restraint selection were based on child's age, not weight.

There are two kinds of error that may occur in the restraint selection process: a child in restraint type A when they have outgrown it, or one who has progressed to restraint type B while still too small. For a given specification of the restraint in terms of the child's weight, an age-based transition will involve a trade-off between these two types of error.

The next Section will give some further introduction to the Standards for child restraints and to the strategies for promoting their use that have been adopted by various jurisdictions. Then a methods Section will describe the calculation of the numbers of children who would fall outside the weight ranges of the Standards, were graduation from one restraint to another to occur at a particular age. This calculation is based upon published data on the weights of children of different ages. Then come results, discussion and conclusions Sections.

RESTRAINT STANDARDS AND ADVICE TO PARENTS

Whether or not a selection error has occurred is determined by a combination of the child's size (usually weight) and the standard under which the restraint was designed and manufactured. All child restraint standards are written to require restraints of a certain class to adequately protect children of a certain size range. Table 1 shows the classification of major restraint types in several standards used in

the USA, the EU and Australia/New Zealand. FMVSS 213 is does not explicitly categorise restraints in the way that UN ECE R44 and AS/NZS 1754 do. However, the weight categories listed in Table 1 reflect the most straightforward interpretation of FMVSS 213.

Notable in the various standards is the fact that restraint requirements are defined in terms of weight, and sometimes height (not listed in Table 1), rather than age. The logic of this is seemingly obvious given that the requirements of a design standard are engineering ones, and that manufacturers must ensure that their products can adequately protect children of the relevant sizes. But while the objective of any design standard on child restraints is to ensure adequate levels of protection offered by a compliant restraint, the objective of promotion and education is rather different: it is to assist in maximising the rate of correct restraint selection and use.

Restraint promotion aims to improve compliance. Practices vary from country to country. For example, the (U.S.) website BoosterSeat.gov suggests promoting children from infant carriers after they are 12 months of age, from a forward facing child restraint at 40 pounds weight and from a booster at 8 years. Recent practice in Australia has been to promote use on the basis of the child's weight, in a way that clearly represents the criteria contained within the applicable Australian Standard. In Australia, age-based recommendations on child restraint transition have fallen out of favour, and the most important factor was the perception that age is too crude a proxy for the dimensions of a child that really matter in relation to appropriate restraint fit.

However, AS/NZS 1754 specifies overlaps in weight between restraint types. The intent of this might have been to allow all children to graduate to a restraint at a similar age, with the lower and upper ends of the weight range chosen to cater for the smallest and largest children graduating to that restraint at the specified transition age. (And if that was not the intent, at least it is a coherent strategy.) If so, the consequence of promoting restraint use on the basis of age, in conjunction with a well-coordinated design standard, should be that relatively few children beyond the low or high end of each weight range should be using any particular class of restraint. Promoting the weight ranges themselves may in fact be inconsistent with one of the purposes of such design standards, given the pressure from children themselves to graduate from something that is more babyish to something that is more adult.

Some aspects of the promotion of restraint selection based on the child's weight are advantageous: the advice is a straight rendering of the relevant design standard, and variation in children's sizes by age becomes irrelevant.

However, there are also disadvantages to weight-based promotion and advantages to age-based promotion.

Firstly, where overlapping weight ranges exist and are promoted, advice is ambiguous and might be confusing: where within the transitional weight range should the transition to the next restraint be made? It is possible that such advice might, because of its ambiguity, encourage transition at too early a stage – as children typically want! And there is empirical evidence that the advice is not memorable. A recent survey in Adelaide, Australia, found that the large majority of respondents could not cite the weight criteria (Edwards et al., 2006).

Secondly, surveys of restraint use have found that

Table 1.
Weight ranges by restraint categories in child restraint Standards

Restraint type	FMVSS 213[1]	UN ECE R44.04	AS/NZS 1754:2004
Infant restraint	0-10 kg	0-10 or 13 kg[2]	0-9 kg
Forward facing child restraint	10-18 kg	9-18 kg	8-18 kg
Larger restraint/booster seat	18-29.5 kg	15-36 kg[3]	14-26 kg

[1] FMVSS 213 does not strictly categorise seat types except for infant-only restraints. Rather, weight specifications for individual seat models determine what dummies should be used for compliance testing. And concerning the upper weight limit of the booster seat, this has been inferred from the requirement of the seat to accommodate a weighted 6-year-old dummy in a dynamic test (NHTSA, 2006). (Models of seat rated to well beyond the limit are available in the US market, and hence 29.5 kg represents a conservative upper limit for booster seat use in the USA.)
[2] Two types specified: Group 0 and Group 0+
[3] Seats fitting into Group 2 and Group 3

many parents do not know even the approximate weightes of their children (Apsler et al., 2003; Edwards et al., 2006). Quite low skill of parents in estimating the weight of their children is also documented in the context of deciding upon an appropriate dosage of medication (Leffler and Hayes, 1997; Goldman et al., 1999; Harris et al., 1999). An average figure from that literature is that parents are in error by more than 10 per cent in 27 per cent of cases. In a similar vein, child restraint surveys also find that many drivers are unable to suggest the height of the children they are transporting (Edwards et al., 2006; Ebel et al., 2003a). To follow weight and height guidelines, parents would need to regularly monitor the weight and height of their children (which in turn necessitates having the tools at their disposal to do so).

Thirdly, it may be easier for the parent to get the child to accept waiting until a concrete figure such as 4 years, rather than the ill-defined moment implicit at the present. (With the present concern over childhood obesity, it is obviously unacceptable for the concrete figure to take the form of a weight.)

Criteria for restraint transition should be simple, definite, and memorable (e.g. 12 months, 4 years and 8 years). This would make promotion of child restraints and the specification and enforcement of legislation easier than at present.

However, there would be some negative consequences of using age-based recommendations, and these should be quantified. It is unlikely that every child would be catered for and the smallest and the largest children might be misclassified by such an approach. The level of misclassification depends upon the relevant design standard, the age chosen for transition from one restraint type to another and the distribution of weights (and other dimensions) at various ages. The following analysis quantifies the misclassification with respect to weight that would arise using age-based advice.

METHODS

Anthropometric data

A convenient source of data on the distribution of children's weights is provided by the U.S. Centers for Disease Control and Prevention (Ogden et al., 2002), which is based on the US National Health and Nutrition Examination Survey (http://www.cdc.gov/nchs/nhanes.htm). This source is easy to use because it summarises the weights of each one-month age cohort using three parameters.. Although the dataset describes children in the USA, it is also used in Australia as a reference for normal growth patterns in children (Department of Human Services, State Government of Victoria, 2006). It could be replaced by data from other jurisdictions if required.

Summary of each weight distribution is by the LMS method (Cole, 1990). For each one-month age cohort of surveyed children, Ogden et al. (2002) calculated three parameters: the coefficient of the Box-Cox transformation (L), which transforms the data to a nearly normal distribution, the median (M) and the generalised coefficient of variation (S). For a given weight u, the proportion of children of a certain age, weighing more or less than u, can be obtained by determining the z-score corresponding to the age cohort i. Given L, M and S, the z-score is given by

$$z = [(u/M)^L - 1]/LS \qquad (2)$$

After calculating z, it is straightforward to find the proportions that lie either side of u, using statistical tables or a computer package. These proportions are the functions $F_i(u)$ and $1 - F_i(u)$.

The growth data from the CDC is tabulated separately for boys and for girls, and so proportions are calculated for girls and boys, then averaged.

Trade-off analysis

We envisage a sharp age transition between restraint types, not a band of ages (because, children being what they are, this will degenerate to the youngest age in the band). We will examine the numbers of children who would be in the wrong restraint for their weight. To do this, we use a dataset giving the distribution of weight amongst the population of male and female children at each month of life. For each potential transition age, we calculate the number of children that would be in the wrong restraint (misclassified) according to their weight: those under the transition age but too large for the pre-transition restraint, and those over the transition age but too small for the post-transition restraint. Any choice of a transition age will entail a trade-off between the two classes of misclassification, but an age can be chosen that minimises their sum. We shall examine these numbers in relation to the three design standards given in Table 1: FMVSS 213, UN ECE R44.04 and AS/NZS 1743:2004.

Consider the following situation.

- A child progresses from one restraint (device A) to a larger restraint (device B) at some well-defined and precise age y.
- The relevant design standard is written to ensure that A is satisfactory for children

who have a dimensional value (e.g. weight) of $u = a$ or less.

- Similarly, B is satisfactory for a child with a dimensional value of $u = b$ or greater.

Note that b may be less than a, providing some transitional overlap. However, the overlap may be non-existent ($a = b$) or even negative ($a < b$).

Our notation will be that the proportion of children with a dimensional value less than u within the age cohort i is $F_i(u)$. The convention we shall adopt is that a child in their ith month of life is in the one-month cohort i. The transition between restraint types occurs at the end of month y. (For example, a transition at 6 months of age occurs at the end of a child's 6th month of life.)

If all children progress from the first restraint to the second at age y, the number of children in an "incorrect" restraint, P, is given by

$$P = \sum_{i=0}^{y} 1\text{-}F_i(a) + \sum_{i=y+1}^{\infty} F_i(b) \qquad (1)$$

The total number of children misclassified (in units of the number of children in a month cohort) is the sum of children that are aged less than y that are too large for A, and those that are aged more than y that are too small for B. Hence, P in Equation 1 describes the total misclassification, while the two sums refer to the number of children using A who are too large and the number of children using B who are too small. These quantities are illustrated in Figure 1.

It is possible to determine P and its two components for different choices of the transition age y. The two sums, representing the number of children too large for A and the number of children too small for B, represent the trade-off that must be made if restraint transition is to be made at a certain age. Plotting one sum against the other shows how the trade-off is affected by the choice of transition age and indicates the age at which the total P is minimised. The trade-off graph is illustrated in Figure 2.

We assume that for children of weight less than a, restraint A is satisfactory. Further, that for children of weight greater than a, restraint A is unsatisfactory. And we assume a sharp change for B also. This is unrealistic; it is likely that "satisfactory" is correct and "unsatisfactory" is an exaggeration, and thus our results will overstate the true number of inappropriately restrained children. However, it is not the aim here to examine actual rates of so-called appropriate restraint use that might ensue from age-based transitions, but to examine how children's weights would comply with restraint specifications.

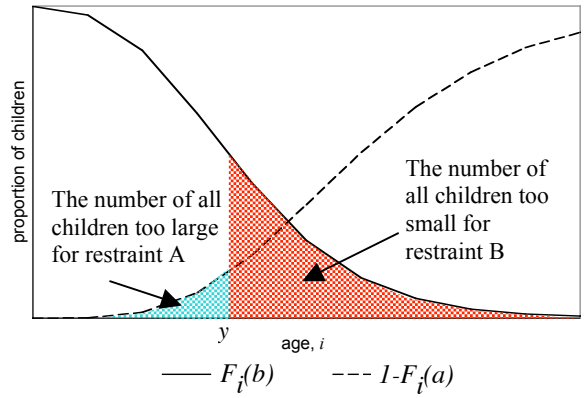

Figure 1. The shaded area is the total number of children that would be misclassified (according to their size) into restraints A and B, if all children were to move from restraint A to restraint B at age *y*.

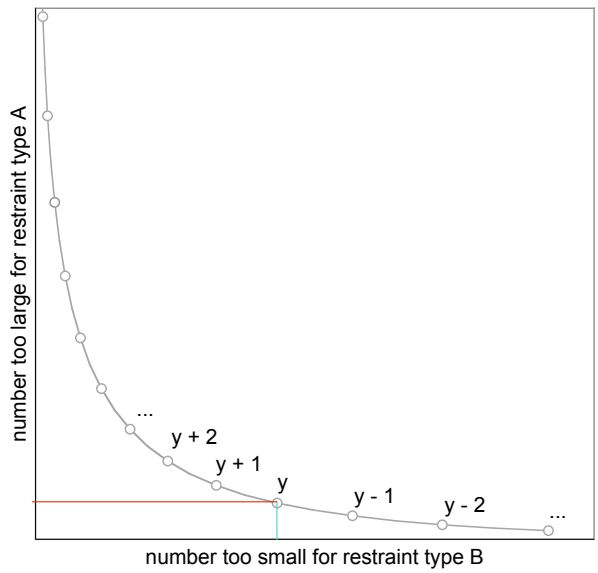

Figure 2. The trade-off graph showing the two proportions shaded in Figure 1 plotted against one another for different values of the transition age *y* (in months).

Incidentally, it not necessary that a and b describe the same dimension: one may describe weight, and the other seated height or any other relevant measurement. All that is required is knowledge of the distribution of the dimension at different ages.

An extended interpretation of Equation 1

When considering the effects of misclassification, the following two assumptions make a natural starting point.

- There is a sharp change from a restraint being satisfactory to being unsatisfactory if the child is fractionally too small or too large was assumed.
- Being too big for device A and being too small for device B are equally serious.

We will express our results above in terms of the numbers of children of an age range who fall outside the specification of a restraint, and thus are misclassified by age to an inappropriate restraint type. The above assumptions will thus be by-passed. Nevertheless, let us sketch how they may be relaxed, so that the effects of misclassification could be studied. This may be done by introducing the idea of a misfit penalty function.

For device A, let the penalty from misfit be a non-decreasing function of child's dimension u, $M_A(u)$, for $u > a$ and 0 for $u < a$. And for device B, it is a non-increasing function of u, $M_B(u)$, for $u < b$ and 0 for $u > b$. Earlier, in writing Equation 1, $M_A(u)$ and $M_B(u)$ were in effect both taken as 1. The total misfit for children younger than y but bigger than a is the sum over all weights bigger than a and all ages younger than y of the product $f_i(u)M_A(u)$, where $f_i(u)$ is the proportion of children of age i who are of weight u. Similarly, the total misfit for children older than y but smaller than b is the sum over all weights less than b and all ages older than y of the product $f_i(u)M_B(u)$. A trade-off graph similar to Figure 2 could be obtained by making several different choices of y.

Ideally, M_A and M_B would reflect the increase in risk associated with being too small or too big for the restraint, but this probably goes beyond what current data can support.

RESULTS

Transition from infant restraints to forward facing child restraints

AS/NZS 1754:2004 requires infant restraints to satisfactorily restrain children from birth to 9 kg in weight. It requires forward facing child restraints to satisfactorily restrain children whose weight lies in the range of 8 to 18 kg. Therefore, to examine the transition from infant restraints to forward facing child restraints we calculate P by setting $a = 9$ kg and $b = 8$ kg.

UN ECE R44,04 differs from AS/NZS 1754 in that infant restraints built under those standards are required to accommodate children to 10 kg, and forward facing child restraints from 9 kg. For this standard, P will be calculated by setting $a = 10$ kg and $b = 9$ kg.

FMVSS 213 is less prescriptive about restraint classes. However, we believe the usual interpretation is that infants should be transported in rear facing infant restraints to 22 pounds and in forward facing car child restraints from 22 pounds to 40 pounds.

Note that both AS/NZS 1754 and UN ECE R44.04 nominate a one-kilogram overlap weight range, while U.S. practice provides an exact transition weight and no range.

The results of the trade-off analysis are shown in Figure 3. It shows the number of children less than b kg ($F_i(b)$) plotted against those greater than a kg ($1 - F_i(a)$), for various transition ages. The three lines correspond to AS/NZS 1754, UN ECE R44.04 and FMVSS 213.

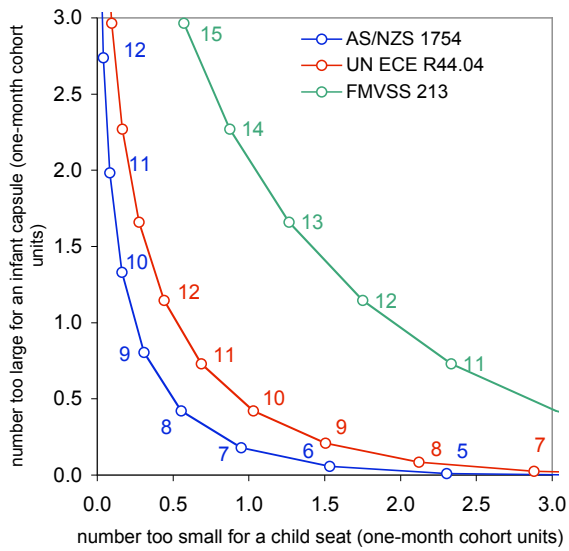

Figure 3. Trade-off graph for age-based transitions from an infant carrier to forward facing child restraint. The data points are labelled with the transition age (months). The three lines refer to (from bottom to top) Australia (b = 8 kg, a = 9 kg), the EU (b = 10 kg, a = 9 kg) and the US (a = b = 10 kg).

To illustrate the utility of this Figure, consider a recommendation under AS/NZS 1754 to move children from an infant restraint to a forward facing child restraint at 6 months of age. Figure 3 shows that a very small number will have exceeded the upper weight limit of the infant carrier at this stage; it is a number equivalent to 0.06 of a one-month cohort of children. On the other hand, a larger

number of children do not satisfy the minimum weight specified for a forward facing child restraint: a number equivalent to 1.5 one-month cohorts of children are not yet heavy enough. It might also be seen from Figure 3 that about one-third of these children will not reach the minimum weight after a further 2 months, but very few are still too light at 11 months of age.

If the calculations could be performed for transition ages of fractional months, each line in Figure 3 would be a smooth curve and the optimum would be where its slope equals –1. For AS/NZS 1754, this is evidently at about 8 months of age. Changing the transition age from 6 months to 8 months would theoretically reduce the number of children in forward facing child restraints who are too light by two-thirds. The trade-off would be an increase in the number of children in infant restraints that exceed the upper weight limit. The total misclassification (the number in the wrong restraint for their weight) for a transition at 8 months of age would be equivalent to a single one-month cohort. For 6 months it is 1.5 one-month cohorts.

Now consider the range 9-10 kg specified by UN ECE R44.04. It may be noted that:

- The optimum transition age given the specifications in UN ECE R44.04 is 11 months, rather than 8 months under AS/NZS 1754.
- The total number of children in the incorrect restraint, P, is equivalent to 1.4 one-month cohorts. Transition ages of 10 months and 12 months produce similar numbers for P (1.5 and 1.6).
- Overall, the trade-off line for UN ECE R44.04 lies to the right of, and above, the trade-off line for AS/NZS 1754, despite both Standards specifying a one-kilogram overlap of weights. This is because the variance of the weights of a cohort of children increases as they get older. Hence a greater overlap of weights is required for a higher transition age, y.

Age transition at 12 months under UN ECE R44.04 would mean that 1.15 one-month cohorts would be too large for their restraint. Of children in forward facing child restraints, 0.44 one-month cohorts would be under 9 kg, but the majority of these children would become 9 kg or greater within two months.

Finally, in the line in Figure 3 representing FMVSS 213, we can see the effect of providing no weight overlap. Because FMVSS 213 and UN ECE R44.04 specify the same upper weight limit (10 kg) the ordinate value for each transition age is the same under each Standard. However the abscissa values of the transitions ages are different. For example, given a transition age of 12 months under FMVSS 213, the number of children occupying forward facing child seat that are too light for the seat is three times the number under UN ECE R44.04.

- The optimum transition age given the specifications in FMVSS 213 is 12 months.
- The total number of children in the incorrect restraint, P, is equivalent to 2.9 one-month cohorts.

Transition from forward facing child restraints to booster seats

As mentioned above, as a cohort of children age, the variance in their weights increases and so we should expect an age-based transition from the forward facing child restraint to a booster seat to require a larger overlap than the transition from an infant carrier to a forward facing child restraint. Overlap of specifications for a forward facing child restraint and a booster seat differs from one standard to another: 14-18 kg in AS 1754, 15-18 kg in UN ECE R44 and no overlap with FMVSS 213. Figure 4 shows the number of children less than b kg ($F_i(b)$) plotted against those greater than a kg ($1 - F_i(a)$), for various transition ages. The three lines correspond to AS/NZS 1754 (b = 14, a = 18 kg) UN ECE R44.04 (b = 15 kg, a = 18 kg) and FMVSS 213 ($a = b$ = 18 kg).

The optimum age transitions, where P is minimised, are close to 4 years (48 months) for AS 1754 and UN ECE R44.04. For FMVSS 213, the optimum is close to 5 years of age (60 months), and it is clear that P is much larger for FMVSS 213 specifications than for the other two Standards. About five times as many children would be misclassified for an age based transition under FMVSS 213 as under AS/NZS 1754. Note also that advice mentioning the use of forward facing child seats to 4 years of age (e.g. NHTSA, 2005) is not consistent with FMVSS 213, as many more children are below 18 kg than over 18 kg at this age. The value of P under each Standard is as follows:

FMVSS 213 $P_{y=60}$ = 10.4 one-month cohorts
UN ECE R44.04 $P_{y=48}$ = 3.4 one-month cohorts
AS/NZS 1754 $P_{y=48}$ = 1.9 one-month cohorts

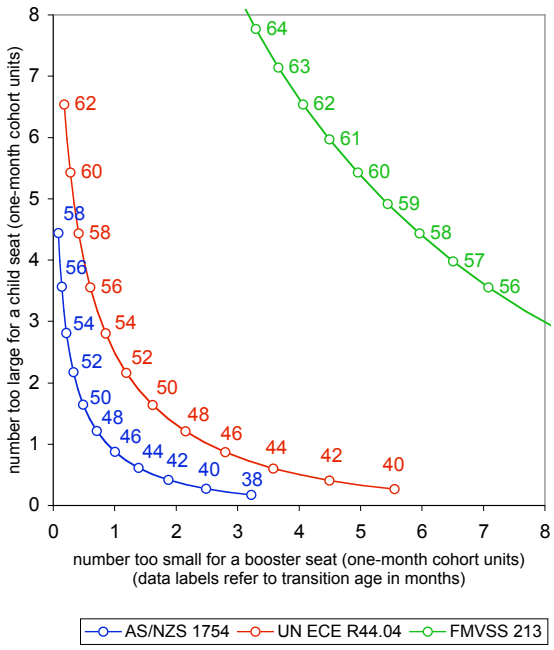

Figure 4. Trade-off graph for age-based transitions from a forward facing child restraint to a booster seat. The data points are labelled with the transition age (months). The three lines refer to (from bottom to top) Australia (*b* = 14 kg, *a* = 18 kg), the EU (*b* = 15, *a* = 18 kg) and the US (*a* = *b* = 18 kg).

Transition from booster seat to adult seat belt

The transition from use of a booster seat to use of an adult seat belt is a subject that may have been given less attention than it deserves, with Standards for child and adult restraints not being fully coordinated with one another. However, we have not conducted a trade-off analysis for this as the design and specification of the adult seat belt is outside the scope of the three child restraint Standards considered in this paper.

Summarising the effect of aged based transitions

Having estimated separately the errors resulting from age-based transitions between infant carriers and forward facing child restraints, and between forward facing child restraints and booster seats, we now summarise the effect and examine the temporal course of misclassification errors. The stage at which a child should cease use of a booster seat is unclear, and may depend of the geometry of the adult restraint specific to the vehicle, but 8 years of age is often used as a guideline. Hence we will examine the error up to that age.

It is straightforward to estimate the proportion of children at each age that exceed the upper weight specification of the booster seat under each Standard by just considering the sum 1 - $F_i(a)$. The value of *a* (the upper weight specification) for booster seats is 26 kg under AS/NZS 1754 (currently under review) and 32 kg under UN ECE R44.04. The application of FMVSS 213 extends to children weighing 65 pounds or 29.5 kg (some models of restraints may accommodate children of a higher weight).

Figure 5 shows the error for each month cohort, when child restraint selection is made on the basis of the ages indicated. Included in this Figure are those children under 8 years of age who are heavier than the upper weight specification of the booster seat.

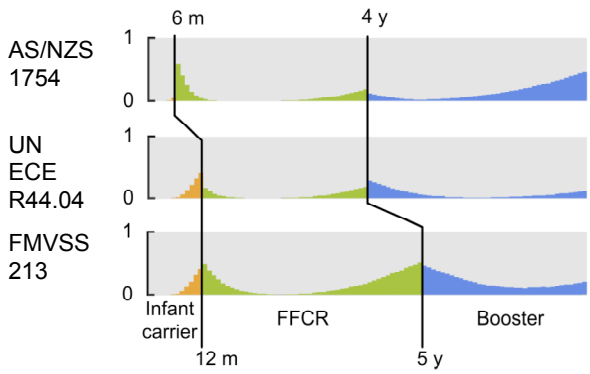

Figure 5. Proportion of each one-month cohort misclassified (too heavy or too light) under the three Standards AS/NZS 1754, UN ECE R44.04, and FMVSS 213, for restraint transitions at the ages indicated (months of life), for all children aged 0-8 years.

In interpreting Figure 5, note that the population to 8 years of age is represented by the area of the shaded boxes, and the coloured areas represent the proportion of the population incorrectly classified to the restraint type. The numbers of children represented by the coloured areas in Figure 5 are given in Table 2, while the proportion of children correctly restrained (represented by the remaining grey area in Figure 5) is given in Table 3.

Table 2.
Number of children (in one-month cohorts) misclassified to child restraint types according to their weight, when transitions are made on the basis of age

Standard	Transition ages	Number misclassified							Percentage of children under 8
		Infant carrier		Child seat		Booster seat		Total	
		Type of misclassification							
		Too light	Too heavy	Too light	Too heavy	Too light	Too heavy		
AS/NZS 1754	6 m, 4 y, 8y	-	0.06	1.53	1.21	0.71	6.28	9.79	10.2%
UN ECE R44	12 m, 4 y, 8 y	-	1.15	0.44	1.21	2.15	1.13	6.08	6.3%
FMVSS 213	12 m, 5 y, 8 y	-	1.15	1.75	5.43	4.96	2.32	15.61	16.3%

Table 3.
Proportion of children in each restraint type who are in the correct mass range, when transitions are made on the basis of ages

Standard	Transition ages	Proportions correctly classified by restraint type			Proportion of children under 8
		Infant carrier	Child seat	Booster seat	
AS/NZS 1754	6 m, 4 y, 8 y	99.0%	93.5%	85.4%	89.8%
UN ECE R44	12 m, 4 y, 8 y	90.4%	95.4%	93.2%	93.7%
FMVSS 213	12 m, 5 y, 8 y	90.4%	85.0%	84.8%	83.7%

DISCUSSION

The ability of age-based transitions to classify children into the correct restraint differs across the three design standards considered in this analysis. The average error ranges from 6.3% of the relevant population (UN ECE R44.04) to 16.3% (FMVSS 213), though the latter estimate is somewhat pessimistic as many models of booster are rated to beyond 29.5 kg. The average errors are not high, although the peaks in the temporal error, occurring around the transition ages can be much higher – up to 50% of a one-month cohort in the case of FMVSS 213 where there is no overlap of weight range between restraint types. It has not been the purpose of this analysis to make conclusions on the increase in risk this error would represent. Rather, we are examining how the compliance of children with seat weight specifications would be affected by recommending a transition on the basis of their age. That is, our purpose has been to explore the consequences of age-based transitions, rather than to positively advocate them. Many children incorrectly classified to restraint types are within 1 or 2 kg of the limit of the weight specification, and it is unlikely that these children are unprotected by their restraints. Noting the transient nature of the error (children growing into the restraint, or graduating to a more advanced restraint), it is unlikely that the increase in risk over the first eight years of life would be substantial.

The differences in the error between restraint types mean that advice to use or refrain from using age in restraint advice is not necessarily transferable between jurisdictions. For example, if a recommendation were to be made to parents to move their children to a booster seat at age 4 in Australia, the consequence for correct restraint selection would be rather different from a similar piece of advice recommending restraint transition at 5 years of age in the United States.

To balance, and perhaps outweigh, the error that age-based transitions produce, two further factors should be considered.

- First, children who obviously outgrow their restraints before the transition age may be graduated to the next restraint by their parents earlier, thus limiting the extent of the problem.

- Second, and more central to this analysis, is the current high rate of incorrect restraint selection that is reported in nearly all surveys of restraint use. Even in Australia where age-based promotion is discouraged, parents consistently and naturally want to nominate an age to identify the stage at which to make the transition from one restraint to the next. And many of those who know weight and height are important are unable to report

the size of the relevant dimensions contained in recommendations.

The transition ages we have chosen to examine in this analysis were 6 months, 12 months, 4 years and 5 years. In some cases these do not exactly align with the optimum age for the weight specifications of each kind of seat. However, if age advice is to be given, it seems reasonable to choose ages that are simple to remember. Any improvements that might be gained by recommending a less memorable transition age would probably be negated by a lower rate of compliance.

Weight is not the sole determinant of correct restraint fit, but the analysis here may be repeated with other anthropometric dimensions to guide all aspects of restraint design. For example, if the distribution of seated shoulder height were known as a function of age in the population, a trade-off analysis could be performed to examine the minimum and maximum slot heights for the shoulder belt harness.

The analysis has taken the Standard as given, and has examined the effect of age-based transitions. A further step would be to take an aged-based transition as given (e.g. at 4 years), and quantify the effect of different overlaps in the Standards. This would remove some of the factors that make it difficult for parents to comply with restraint guidelines, and shift the task to the engineer who is designing the seat. We propose that it should therefore be possible to decide on a simple message for parents – transition on the basis of age – and to then create a design standard to accommodate the large majority of children who complied with the recommendation.

We should also note that a similar method of analysing trade-offs between two types of error could conceivably be applied outside of the child restraint context – to child-proof gates for swimming pools (given the distributions of heights of children and adults), or to child-proof caps for medicine bottles (given the distributions of strengths of children and adults).

CONCLUSIONS

- The consequences for recommending transition on the basis of age are different depending on which standard applies.
- In all cases, the average error is low – 16.3% of children under 8 years of age would be incorrectly specified to their restraint type under FMVSS 213. Lower error rates are produced by specifications AS/NZS 1754 and UN ECE R44.04.
- Even small increases in the overlap of weight ranges specified for restraint types can drastically reduce the error.
- It is possible to use age as the transition criterion if the Standard is designed to support it.
- Overlap of weight ranges optimised for a given age transition can mean that age based transitions can be used with confidence, opening up possibilities for improved promotion, compliance, regulation and enforcement.
- The trade-off analysis presented here may be applied to other anthropometric measures.

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