Many children progress from one type of restraint to the next at too small a size: Should advice to parents be simple and based on child age, with variation in child size accommodated by overlaps in restraint specifications?

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Abstract

Published surveys of child in-vehicle restraint use demonstrate that many children are in an inappropriate type of restraint. In particular, children tend to progress from a forward-facing child restraint to a booster seat at too small a size, and from a booster seat to an adult belt at too small a size. Standards for child restraints are written in terms of their weight, not their age. That leads to advice to parents emphasising the child's weight as the criterion for selecting a type of restraint. This has unfortunately led to advice becoming complicated and confusing. Children tend to want to progress to the next restraint earlier rather than later, and take advantage of lack of clarity. Moreover, many parents do not know the weight of their child. In this paper, we explore what might be the consequences of very simple advice, such as: change the type of restraint at 6 months, 4 years, and 8 years. Obviously, children differ in size. This may be allowed for by writing the Standard so that the restraint is suitable both for a small-for-age child at the youngest age and a large-for-age child at the oldest age. Our method uses the distribution of children's weights at different ages. Given that, and given also the range of weights for which each restraint is appropriate, we work out how many children would be in an inappropriate restraint if progression were at particular ages. This turns out to be much less than the number observed under the current regime of weight-based advice.

1. Introduction

Published surveys of child in-vehicle restraint use demonstrate that many children are in an inappropriate type of restraint. In particular, children tend to progress from a forward-facing child restraint to a booster seat at too small a size, and from a booster seat to an adult belt at too small a size. We noticed this when conducting a survey of what types of restraints are used (Edwards et al., 2006; Anderson et al., 2006). In that survey, we did not actually measure children's weights --- but, knowing how old they were, we did some calculations and came to the conclusion that any reasonable assumption about weights-for-age makes clear a mismatch between their weights and the restraints they used. There is plenty of other evidence of this (Apsler et al., 2003; Decina and Knoebel, 1997; Ebel et al., 2003; Ramsey et al., 2000; Charlton et al., 2006). We also found that many parents (or, more correctly, many drivers of the cars transporting the children) did not know the weights of their children. For a review of child restraints with particular reference to Australia, see Reeve et al. (2007).

Child restraints are designed to be suitable for children within a certain weight range, not an age range, and the Standards are written that way. Thus it might seem natural for advice to parents to emphasise the child's weight as the criterion for selecting a type of restraint.

Unfortunately, this has led to advice becoming complicated and confusing. Children tend to want to progress to the next restraint earlier rather than later, and the fact that this happens so frequently may be because they take advantage of lack of clarity. And, as already mentioned, many parents do not know the weight of their child. This has also been found in other child restraint surveys and in different contexts (Apsler et al., 2003; Leffler and Hayes, 1997; Harris et al., 1999). Very likely, there are some places where parents do know the heights and weights of their children, e.g., Japan, where there is thrice-yearly measurement by school nurses (Sekine et al., 2002).

In this paper, we explore what might be the consequences of very simple advice, such as: change the type of restraint at 6 months, 4 years, and 8 years. Obviously, children differ in size --- but this may be allowed for by writing the Standard so that the restraint is suitable both for a small-for-age child at the youngest age and a large-for-age child at the oldest age. Our method uses the distribution of children's weights at different ages. Given that, and given also the range of weights for which each restraint is appropriate, we work out how many children would be in an inappropriate restraint if progression were at particular ages. This turns out to be much less than the number observed under the current regime of weight-based advice. We have given another account of this work in Anderson and Hutchinson (2007).

The remaining Sections of this paper are as follows.

2. Restraints and Standards for restraints.
3. Formulation of the question, and method of answering it.
4. Choice of transition age.
5. Results: Transition from infant capsule to FFCR.
6. Results: Transition from FFCR to booster seat.
7. Transition from booster seat to adult belt.
8. Effect of change to Standards.
9. Overview of different methods of illustration.
10. Discussion.
11. Concluding remarks.

2. Restraints and Standards for restraints

In Australia, the main types of in-vehicle child restraint are as follows.

- Infant capsule (rearward-facing infant restraint), known as type A1.
- Forward-facing child restraint (FFCR), which has an integral harness --- type B.
- Booster seat (or booster cushion), which positions the child so that an adult seatbelt can be used safely. (Some booster seats have a back.) This is known as type E.

Australian Standard 1754 specifies that these must respectively be suitable for children weighing 0-9 kg, 8-18 kg, and 14-26 kg.

Elsewhere in the world, Standards have been written differently, and not necessarily in ways that are easily comparable to Australian practice. But, roughly speaking, the European Union employs weight ranges of 0-10 kg, 9-18 kg, and 15-25 kg, and the U.S.A. employs weight ranges of 5-22 lb, 20-40 lb, and 40+ lb.

Historically, Standards for child restraints have not been well coordinated with Standards for adult seatbelts. It is tacitly assumed that children will graduate to an adult belt at 7 or 8 years --- but at this age, they are appreciably smaller than a 5th percentile adult female, which is the smallest size that adult belts have to be satisfactory for. Furthermore, in practice, adult belts are used for many children as young as 4.

3. Formulation of the question, and method of answering it

3.1 The question

If children changed from one restraint to another at a specific age, how many would be in the wrong restraint? Notice this question refers to a sharp transition age --- no mention of an age range or a weight range. Once this question is formulated, the general lines by which we proceed become clear.

- We need to know how many of the children younger than the transition age are too big for the first restraint.
- And we need to know how many of the children older than the transition age are too small for the second restraint.

We assume that a particular type of restraint, such as an FFCR, is suitable for a particular range of weights of children, and unsuitable for other weights. Unsuitable does not mean utterly unsafe, and suitable does not mean ideal. The analysis below could be modified by utilizing a "suitability function", but that would be unnecessarily complicated for present purposes. (In effect, we are assuming suitability is 1 for some range of weights, and 0 for other weights.) Instead of weight, the analysis could be adapted to height, or sitting height, or shoulder width, provided data on these measurements were available. Again, we do not pursue this possibility.

We also assume that the distribution of children's weights at different ages is known. Specifically, we will assume that the data from the Centers for Disease Control and Prevention in the U.S.A. (Ogden et al., 2002) can be used. In this dataset, children are disaggregated by sex and one-month cohorts of age.

Are the sizes of boys very different from those of girls? Do children from different ethnic backgrounds differ much in size? The data that we have seen suggest that differences are not sufficient for it to be worthwhile destroying the simplicity of advice in order to tailor it to a particular sex or ethnicity.

Notation concerning the restraint. A child changes from restraint A to a larger restraint B at age y. Restraint A is satisfactory for children whose weight u is a or less. Restraint B is satisfactory for a child whose weight u is b or greater.

Notation concerning the child. In the ith month of life, the child is in one-month cohort i. For this cohort, the proportion of children whose weight is less than u is $F_i(u)$. Change from restraint A to B occurs at the end of month y.

The function F. For fixed i and regarded as a function of u, F describes the variability of children at a given age; statisticians would call it the cumulative distribution function of weight. For fixed u, F decreases as a function of i: it reflects the growth of children with age by describing the falling proportion who are smaller than a given weight u.

3.2 The answer

At this point, we consider we have covered the difficult part of the topic, setting up the question. Once this has been stated --- with no fuzziness from a weight range or an age range, or doubts about whether a restraint is as suitable for a child close to the transition as it is for a child in the middle of its specified range, and with disaggregation of children into age bands of one month each --- working out the answer proceeds smoothly.

First, consider children younger than y. These are in restraint A. The proportion of cohort i who are too big for restraint A is $1-F_i(a)$. The relevant one-month cohorts are those up to and including y. The total number of children (in units of the number in a single month cohort) is $\sum_1 [1-F_i(a)]$, where $\sum_1$ denotes summation from $i = 1$ (or the previous transition) up to $i = y$.

Second, consider children older than y. These are in restraint B. The proportion of cohort i who are too small for restraint B is $F_i(b)$. The total number of children is $\sum_2 F_i(b)$, where $\sum_2$ denotes summation from $i = y+1$ up to the next transition.

The total number of children who are either younger than y but too big for A, or older than y but too small for B, is the sum of these, $\sum_1 [1-F_i(a)] + \sum_2 F_i(b)$.

This total is a function of y, a, and b. Given these, and knowing the function $F_i(u)$ from Ogden et al. (2002) or some other source, the total may easily be worked out.

4. Choice of transition age

The quantities a and b reflect the Australian Standard and are characteristic of the restraints available. Standards can be rewritten and restraints can be redesigned, but the easier issue to tackle is what the age y should be.

As y increases, the number of children in A but actually too big for it increases, and the number in B but actually too small for it decreases: there is a trade-off. It is possible to identify an age at which the sum is minimised.

In principle, this could be generalised to a total unsuitability score, but we doubt whether anyone knows how the unsuitability of being (say) 2 kg too heavy for one restraint compares with the unsuitability of being 1 kg too light for another, and so we do not pursue this. We simply assume that if a restraint satisfies a Standard, it is suitable for the weight range mentioned in the Standard and unsuitable for other weights.

5. Results: Transition from infant capsule to FFCR

5.1 Step 1: Consider one particular choice of transition age

For the transition from infant capsule to FFCR, in Australia a is 9 kg and b is 8 kg. Suppose that the transition age is y = 6 months.

Boys, cohorts 1 to 4. Very few of these are too big for an infant capsule (i.e., exceed 9 kg).
Boys, cohort 5. Some 2 per cent of these exceed 9 kg.
Boys, cohort 6. Some 8 per cent of these exceed 9 kg.
Boys, cohort 7. Some 43 per cent are too small for an FFCR (i.e., are less than 8 kg).
Boys, cohort 8. Some 25 per cent are less than 8 kg.
Boys, cohort 9. Some 13 per cent are less than 8 kg.
Boys, cohort 10. Some 6 per cent are less than 8 kg.
And so on.

Total misclassification is 103 per cent of a one-month cohort of boys, made up of 10 per cent who were too big for the infant capsule in the month or two before the transition, and 93 per cent who were too small for the FFCR in the months after transitioning. Thus the total misclassification is around 9 per cent of boys in their first year of life.

A similar calculation can be made for girls.

5.2 Step 2: Repeat the calculations for different transition ages

The calculations can be repeated for different choices of the transition age y (5 months, 7 months, 8 months, and so on).

There are two forms of visual presentation of the results that are quite helpful.

- Having calculated the total number of children (in units of one-month cohorts) who are too large for restraint A and the total number who are too small for restraint B, these numbers can be plotted one against the other, the different data points corresponding to different ages of transition, *y*. As *y* increases, so the first of these numbers increases and the second decreases: there is a trade-off between them. One wants to select the point on the graph that is closest to the origin, i.e., where the sum of these proportions is minimized. (If it is considered plausible that one type of misclassification is more serious than the other, one could consider a generalized sum is which one misclassification is given more importance than the other.)
- The sum can be plotted against transition age *y*. Naturally, this presupposes that one is comfortable with the idea that the two types of misclassification are equally important.

It turns out that the sum is minimised at 7 months for boys and 9 months for girls. The improvement from 6 months is not great enough that we would recommend changing from this, however. See Table 1.

6. Results: Transition from FFCR to booster seat

The method of calculation for the transition from a forward-facing child restraint to a booster seat is similar to that in Section 5, and some results are in Table 2.

7. Transition from booster seat to adult belt

As mentioned in Section 2, there has been something of a disconnect between Standards for child restraints and Standards for adult seatbelts. This has become of concern to an increasing number of people in recent years, with it being suggested that an adult belt is only suitable once the child has reached 145 cm in height. Possible solutions include: ensuring that adult belts are suitable for smaller people than the 5th percentile adult female (e.g., the average 7 year old), developing booster seats suitable for bigger children (e.g., the average 12 year old), or a compromise between these strategies.

To proceed with an analysis similar to those for earlier transitions, we would need to know how unsatisfactory a standard booster seat is as a function of weight (over the range 26-40 kg, say), and also how unsatisfactory an adult belt is as a function of height (over the range 120-145 cm, say). But this probably goes beyond what can be confidently supported.

Table 1. Numbers of children misclassified (in units of a one-month cohort), for various choices of the transition age from an infant capsule to an FFCR.

Age of transition, y (months)	Number of children misclassified: Too big for the first restraint	Too small for the second restraint	Total
6	0.06	1.53	1.59
9	0.80	0.31	1.11
12	2.74	0.04	2.78

Table 2. Numbers of children misclassified (in units of a one-month cohort), for various choices of the transition age from FFCR to booster seat.

Age of transition, y (months)	Number of children misclassified: Too big for the first restraint	Too small for the second restraint	Total

36	0.11	4.09	4.20
48	1.22	0.70	1.92
60	5.45	0.04	5.49

8. Effect of change to Standards

The calculations above take *a* and *b* as known, and examine what effect *y* has. To complement this, we might suppose that *y* has been fixed at some memorable and convenient age (such as 4 years), and ask how *a* and *b* affect the proportion of children misclassified.

- Comparison can be made of the present Australian, European, and U.S. Standards.
- And we may examine what would be the effect of a change to *a* and/or *b* in the Australian context.

See Anderson and Hutchinson (2007) for more on this.

If *a* exceeds *b*, there is overlap in the weight ranges for successive restraints. This is the case for some Standards but not for others. Overlap will mean that a sharp age transition will lead to fewer misclassifications by weight. Thus having an FFCR suitable up to 40 lb and a booster seat suitable only from 40 lb upward, as in the U.S.A., is not well-suited to a sharp age transition. (However, we are simplifying what the U.S. system is, and may be exaggerating the unsuitability.)

Children vary more when they are older and bigger than when they are younger and smaller. Consequently, a given amount of overlap (e.g., 1 kg) is more useful at a younger age and smaller size.

For the FFCR-to-booster transition in Australia, *a* is 18 kg and *b* is 14 kg. If *y* = 48 months were chosen as the transition age, the number of children misclassified would be about 2 one-month cohorts (Table 2). Keeping *y* the same, if *a* were 19 kg and *b* were 13 kg, the number of children misclassified would be reduced to about 0.8 one-month cohorts.

Once one has programmed the calculation, it is easy to compute the result for a grid of values of *a* and *b*. Then the results can be presented as, for example, a contour plot. The effect of specifying different *a* and *b* in the Standard can then easily be seen.

9. Overview of different methods of illustration

It may be useful to list a number of ways of illustrating the calculations and their results that have been mentioned, either implicitly or explictly.

- There is variability in the size of children at any given age. This is described by *F*, regarded as a function of *u* for fixed *i*; statisticians would call *F* the cumulative distribution function of weight. (See Section 3.1.)
- Children grow. This is described by *F*, regarded as a function of *i* for fixed *u*. (See Section 3.1.)
- As different transition ages are considered, so the proportions of children too big for restraint A and too small for restraint B vary in opposite directions. They can be plotted one against the other to demonstrate the trade-off. (See Section 5.2.)
- The two proportions of misclassifications can be added together and plotted versus transition age. (See Section 5.2.)
- Greater overlap in the weight ranges for successive restraints (i.e., *b* exceeding *a* to a greater extent) will mean fewer misclassifications. This can be shown by, for example, a contour plot, the axes being *a* and *b*. (See Section 8.)

10. Discussion

The implication of the way we worded the central question (Section 3.1) is that advice to parents can be very simple and directive. For example, it might be to switch the child from one restraint to the next at 6 months, 4 years, and 8 years. No mention of weights, no mention of ranges, no mention of big-for-age or small-for-age. (We can imagine that it would be appropriate to include information about where to find expert assistance if the child is very unusually sized or shaped, or if there are closely-spaced children in the family.)

The Standards describing successive restraints would need to have overlapping weight ranges, so that a big-for-age child can use restraint A and a small-for-age child can use restraint B. We are placing the responsibility for exercising expertise --- accommodating the range of different sizes and shapes of children --- with the designer and manufacturer of the restraint, not with the parent. That seems to us to be entirely appropriate.

To some people working with child restraints, our line of argument comes as a bit of a shock. A particular restraint is designed for children within a certain weight range, and perhaps within a range of lengths or sitting heights or shoulder widths, and it seems obvious that for a particular child, a restraint should be selected on that basis.

Our response is in two parts. First, surveys show that many children --- the majority of children in some age bands --- are in an unsuitable restraint. The present system of restraints and their promotion to parents does not seem to be working very well. Second, we point to examples of present-day publicity and educational materials directed to parents. These often have a lot of numbers on them --- weights, ages, perhaps heights --- and to us it is not surprising that parents get confused (even if they know their child's weight, which many do not). Actually, we have examined some publicity material from a decade or two ago, and in some respects it resembles what we are suggesting, giving prominence to non-overlapping ranges of age.

We should address two possible weaknesses in our argument.

- First, it could be that for designers and manufacturers, it would be very difficult if Standards prescribed an overlap of weights. We are fairly confident in dismissing this. There are small overlaps in the Australian and European Standards at present, and informal discussions lead us to believe the overlaps could be made a little greater without difficulty. Indeed, the dummy specified in the Australian Standard for dynamic testing of the FFCR weighs 22 kg, even though the specification otherwise requires suitability for an 18 kg child.
- Second, our calculations assume compliance with the directions to graduate the child from one restraint to the next at a particular age. It could be said that it is not fair to compare results from a theory that assumes compliance with results observed in the real world where many parents and children are not complying with the advice available. We cannot give a complete answer to this, in the sense of proving that there would be compliance with firm directives. We can only appeal to common sense notions that clear advice is easier to understand than complicated advice, that advice in terms of something that parents know (child's age) is better than advice in terms of something parents often do not know (child's weight), and that similar factors apply in respect of children's wishes and demands.

11. Concluding remarks

In the title of this paper, we asked a question. Should advice to parents be simple and based on child age, with variation in child size accommodated by overlaps in restraint specifications? At such an early stage of considering this, we do not want to positively advocate a "yes". We go no further than noting that our calculations have not established that

this would be a silly strategy. Using weight as the criterion seems like common sense when the restraint itself is in one's mind. But if the problem lies with parents' and children's knowledge and their utilisation of that knowledge, the simplicity and salience of age increase its attraction as a criterion.

The present situation, with a high rate of premature graduation to a booster seat and to an adult belt, is unsatisfactory. We are suggesting a strategy for remedying this that puts the child's age --- well known to adults and highly salient to children --- at centre-stage. What we have done is:

- Demonstrate in our survey and by reference to other surveys that there is a problem at present.
- Formulate a question concerning what might happen if there were sharp ages of transition.
- Answer that question, finding that the proportion of misclassified children would be low with the present Australian Standards, and could be even lower if there were greater overlap in the weight ranges of different types of restraint.
- Informally check with experts on restraint design and manufacture that they do not regard greater overlap as impracticable.

What we have not done is:

- Prove that there would indeed be good compliance with sharp ages of transition.

Regarding the last point, the natural first step, before taking matters further, would be to listen to what experts on the promotion of health advice to the general public have to say about the merits or otherwise of simple directives based on child age.

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