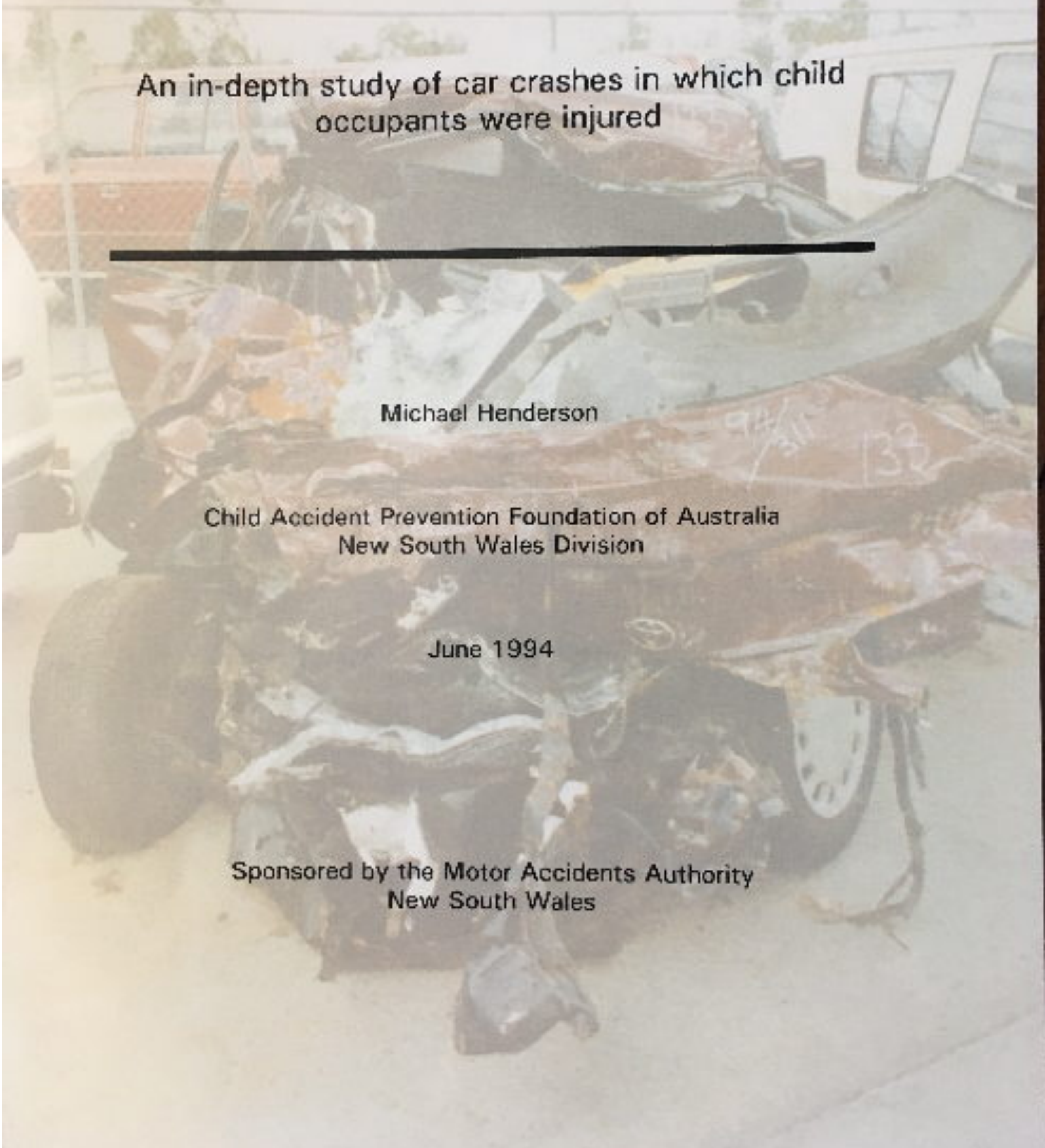
CHILDREN IN CAR CRASHES

An in-depth study of car crashes in which child occupants were injured



Michael Henderson

Child Accident Prevention Foundation of Australia
New South Wales Division

June 1994

Sponsored by the Motor Accidents Authority
New South Wales

CHILDREN IN CAR CRASHES

An in-depth study of car crashes in which child occupants were injured

Michael Henderson

Child Accident Prevention Foundation of Australia
New South Wales Division

June 1994

Sponsored by the Motor Accidents Authority
New South Wales

REPORT DOCUMENTATION PAGE

Report date: June 1994

ISBN: 0 949630 31 4

Pages: 118

Title and subtitle: Children in car crashes: an in-depth study of car crashes in which child occupants were injured

Author: Henderson, Michael

Performing organisation: Child Accident Prevention Foundation
NSW Division
RTA Building, 111 George Street
Parramatta NSW 2150, Australia

Sponsors: Motor Accidents Authority
Level 12, 139-141 Macquarie Street
Sydney NSW 2000

Abstract:

Throughout 1993 in New South Wales, Australia, an in-depth crash investigation team followed up 131 crashes involving 247 children aged 14 or under as passengers. The usage rate of child restraints and adult belts by children is at a very high rate in New South Wales. The research question was whether overall system efficiency could be improved by detecting deficiencies in the effectiveness of individual restraints, and identifying ways to counter them. The sample was composed of three groups: children attending emergency departments (whether injured or not) in the greater Sydney region, fatally-injured children from anywhere in the state, and children riding in cars in which any adults were killed. Data were obtained from examination of crashed vehicles, interviews with parents and drivers, police data, and hospital records. It was concluded that the main sources of injury for restrained children were intrusion of the car's structure, contacts with the car's interior, and invasion of the child's space by flying glass and seat-back collapse. Most injuries were minor, to the head and face. Many restrained children survived very high-speed crashes without injury to the neck or other parts, with deceleration injuries confined to bruising from belt loadings. Misuse, although uncommon, was responsible for some serious injuries. The main objective for restraint design continues to be protection of the head and face.

Key words: Children, child injury, safety, child restraint, seat belt, motor vehicle, automobile, accidents, crashes, investigation, research, biomechanics.

CONTENTS

ACKNOWLEDGMENTS

This study was conducted by an especially-contracted team for the Child Accident Prevention Foundation of Australia (NSW Division), with the generous financial support of the Motor Accidents Authority of New South Wales. The willingness of the Motor Accidents Authority (MAA) to sponsor work that in the end should reduce the demands for medical care and rehabilitation of the injured is deeply appreciated.

The study was immeasurably aided by the material assistance provided by the Road Safety Bureau of the Roads and Traffic Authority of NSW. The premises used by the crash investigation team were adjacent to the Road Safety Bureau, which gave us easy access to the expert advice so readily given by RSB staff, especially those of the Crashlab facility.

The assistance of the NSW Police Service is also gratefully acknowledged. Personnel from the service, from the most senior levels down, eased the team's access to vital information to an extent that much of the research could not have performed without this help. In particular, we much appreciated the expert advice and assistance of the Accident Investigation Squads of the Police Service throughout the state. Members of the squads, personally committed to the collection of accurate crash data, went out of their way to assist us.

The Ambulance Service of New South Wales willingly assisted in notification to us of suitable cases for investigation, and the help of the Service and of individual ambulance officers is also gratefully acknowledged.

The data-collection team, who did most of the legwork, was as follows:

Julie Brown, engineer and team leader, on secondment from the Roads and Traffic Authority;

Sophia Stavropoulos, engineer, on contract for the entire period of the project;

Andrew Mathews (behavioural scientist), **Jason Middleweek** (engineer) and **Andrew Skidmore** (engineer) for different periods throughout the period of the project.

Also providing invaluable assistance as a consultant to the project was **Michael Paine**, engineer, especially in regard to the development of the database and data analysis.

FOREWORD

Lorrie Fay Memorial Address

This report forms the basis for the inaugural Lorrie Fay Memorial Address On Children's Injury Prevention, to be delivered by Dr Michael Henderson on June 15, 1994.

Mrs Lorrie Fay, who died in April 1993, founded the Kidsafe Women's Committee in support of the work of the Child Accident Prevention Foundation in New South Wales. The Committee forms an integral part of the Foundation in this state.

She was a passionate believer in the importance of child injury prevention. This belief was demonstrated by her commitment to keeping abreast of developments in the field, by her active membership of the Council of the New South Wales Division and several of its committees, by contributing voluntary labour whenever it was needed and by her tireless work to raise funds to keep the Foundation operating. Mrs Fay instilled this commitment in the members of the Kidsafe Committee, which the Committee has carried through to today.

The Foundation is deeply indebted to her husband, Gus Fay, and to their children for their continuing support.

Funding for the publication of this report has been made available from the Lorrie Fay Memorial Trust, established through Mr Fay, to enable an annual lecture on a significant children's injury topic to be delivered.

EXECUTIVE SUMMARY

RATIONALE FOR STUDY

Australia has a well-established Australian Standard for child restraints, a unique Australian Design Rule regarding fitment of child restraints to motor vehicles, and a high rate of use of restraints for children following the introduction of mandatory-use regulations. At the community level, the efficiency of a restraint system is a function of the usage rate and the effectiveness in preventing injury. Usage rates in Australia - of both child restraints and adult belts - are very high, at over 95%, and thus improvements must be found in improving effectiveness. Because children are still being injured and killed as the passengers of cars that have been involved in crashes it is therefore important clearly to understand how this is happening, to determine whether there are any deficiencies in the performance of safety equipment or the way that it is used and, if so, what measures might be taken to correct such deficiencies.

Accordingly, the Child Accident Prevention Foundation of Australia (CAPFA), New South Wales Division, throughout the calendar year 1993 conducted a research project aimed at studying crashes involving children as passengers. The study was funded by the Motor Accidents Authority of NSW (the MAA).

The project was designed to collect information on the injuries - including minor ones - sustained by children aged 14 years or under who were involved (as passengers in motor vehicles) in a road accident.

This objective included the following considerations:

- to study injuries that occur to children despite the use of different kinds of restraint;

- to estimate, by comparison, the relative effectiveness of different kinds of restraints used by children (including adult belts);

- to study injuries suffered by children not using restraints of any kind;

- to describe the effects in crashes of misuse and poor fitment of child restraints, where that was shown to occur;

- to study survival and injury mitigation in severe crashes.

The study aim was to include for analysis the following cases:

- all fatally injured child occupants from throughout the State;

- any child occupant involved in a crash in which another occupant was killed anywhere in the State;

- and all child occupants presenting to hospitals accepting trauma patients in the greater metropolitan Sydney area.

STUDY METHODOLOGY

A child was usually notified to the study by hospital personnel as a result of attendance at a hospital emergency department. Notification could also have been through the NSW Ambulance Service, predominantly the Sydney Division. Crashes involving a fatality, either to a child or to an adult in the same vehicle as a child, were notified through police channels. Crush damage was measured by a rig incorporating measuring rods. In suitable cases these measurements were used for part of the input into a proprietory computer package of accident analysis programs. The interiors of case vehicles were carefully examined and measurements taken. Of particular interest were restraint and seat belt mountings, webbing loading marks, contact points between occupants and the vehicle interior, and the degree of intrusion into occupant space. A comprehensive set of colour photographs was taken. The participants, normally the responsible parents, were interviewed in regard to the circumstances of the crash, restraint use and so on. In as much detail as possible the crash was then reconstructed, with particular attention to the vehicle in which the child or children were riding.

OVERVIEW OF FINDINGS

For the calendar year 1993, plus a month at each end of it, there were 288 notifications of potentially valid cases. There were often several "cases" in one crash. After excluding crashes for which suitable contacts could not be established, refusals, and invalid crashes (bus crashes, children over the age limit and so on), data for 247 children aged 14 or younger in 131 crashed cars were gathered for the study and became the sample. In addition, some data for 212 older children and adults in the same crashes were also gathered for the purpose of comparison and further estimation of the severity of crashes.

Restraints used by restrained children in the study were as follows: lap/sash seat belt, 121 cases; lap-only seat belt, 35 cases; infant capsule, 6; forward-facing child seat, 38; rear-facing child seat, 4; booster seat, 24.

There were 17 fatal cases in the study, 45 with moderate to critical injuries, and 185 with minor or no injury.

The ages of case occupants (ranging from a few days to 14 years) were distributed quite evenly throughout the range, with a slight bias towards the under-fives. The average age was 6.7 years. The male/female distribution of the children was very even, with 125 males in the sample and 122 females.

Given the distribution of models throughout the vehicle population there was a fairly representative distribution of models throughout the sample, with the only standout feature being the high proportion of injured children who had been riding in a Toyota Tarago or Toyota Landcruiser. This is a reflection of the fact that these "people carriers" are often used to carry large numbers of people, including children, at a time.

Side impacts were the crash configuration most likely to result in significant injury, with 23 of the 68 case children in side impacts (34%) sustaining moderate or greater injuries, and 31 of 135 cases in frontal and near-frontal crashes (23%) resulting in moderate or greater injuries.

INFANT CAPSULES

Few infant capsules appeared in the study. It so happened that the only fatality occurring in a properly fitted and used child restraint was in one of these, but this involved a heavy side impact against which protection would have been exceedingly difficult in the most ideal of circumstances. The baby girl was aged two months, and was properly restrained in the rear centre seating position of a 1984 Holden Commodore that was struck on the right (driver's) side by another sedan at some 30 to 40 km/h, with severe intrusion. The cause of the child's death was head injury. It is likely that the interior surface of the capsule was driven on to the child's head by a combination of the child ramping up the interior of the capsule within the body band, and the intrusion caused by the impacting car.

All the infant capsules in our sample used body bands to restrain the children. While in general these were found to work well, the findings of this study support the move (driven by recent amendments to the Australian Standard) away from the use of body bands with adherent material fastening and towards the use of harnesses, even given the difficulty of restraining an infant in a harness. A child restrained in a body band can slide beneath it. Webbing shoulder straps should help to prevent this movement.

FORWARD-FACING CHILD SEATS

There were 38 children in the sample restrained in these forward-facing child seats with their own harnesses.

The range of ages of children in these restraints was four weeks to 3.5 years, with a mean age of 1.5 years. There were 22 male children and 16 females. All children were comfortably within the upper range of the designated mass and height for this type of restraint. However, there were four children under the recommended mass range. Three of these small children were uninjured in low-speed collisions, but the fourth received critical head injuries in a rear-end collision when seated in an incorrectly-installed restraint. No injuries were detected on medical examination for 16 children in this sub-sample. In 17 cases, injuries were all minor, with maximum AIS scores of 1. This left only five cases where any individual injury was AIS 2 or more, and overall injury severity ISS 5 or more. Of these five, three (two aged two years, and one aged three) were in frontal impacts, one (aged seven months) in a side impact, and one (five months old) in a rear impact.

The worst of these cases was a fatality, the only one among children using a forward-facing child seat. This was a male child, aged just over two years. The adult seat belt had been used to restrain the child and the seat together. As mounted, the configuration of the webbing would have brought the sash portion directly across the neck of the child but some distance away from him, and this is likely to have been what caused the fatal neck injury as he was thrown forwards into the taut webbing.

Another injury that resulted at least in part to poor installation was suffered by a five-month girl in a forward-facing seat in the left rear position of a small sedan. The car was stationary in traffic when hit from the rear by another passenger car, resulting in a ΔV of not more than 30 km/h. The backs of both the driver and passenger seats in the Suzuki collapsed, and the head of the small child swung down on to the head restraint, causing serious brain damage. The child seat had not been properly installed, and the top tether was not fastened.

The neck is the body part of most concern when children are exposed to high crash forces when their torsos are firmly restrained. Several children of around two and three years of age rode out extremely severe frontal crashes without injury to the neck. These were crashes with forces towards the limits of survival for any restrained human, and the children rode them out at least as well as - and generally better than - the adults in the same cars. Taking only cases involving children (all under three and a half years of age) restrained forwards facing in "Type B" child restraints with shoulder harness and top tether, there were four in frontal or near-frontal crashes with a ΔV conservatively estimated after damage measurement of at least 60 km/h who received no significant neck or other injury. Another five similarly escaped injury in frontal crashes with a ΔV in the range of 50 to 60 km/h.

When children are injured in forward-facing Type B child restraints with harnesses and top tethers, injury is most likely to be a result of intrusion, contact with nearby parts of the vehicle's interior and other occupants, invasion of the child's space by collapsing seat backs, flying glass and other such mechanisms. The only injuries caused by deceleration alone were bruising and abrasion from loads imparted from harness and seat-belt webbing, and some minor internal injuries.

The head remains the most important part of the body to be protected. The child is at risk if allowed to move out of its survival space, and restraint design should place a high priority on the minimisation of excursion of the upper body in order to prevent head contact.

Given the very high protective capacity of dedicated child restraints, parents should be encouraged to use them until the children the child approaches the maximum approved mass, or is manifestly too big for the seat. At present, the indications from this study are that parents move children out of the seats and into adult belts too early.

BOOSTER SEATS

The performance of well-mounted booster seats was found to be good. Unfortunately, the booster seat is open to a very dangerous form of misuse: namely, the use of the booster with a lap belt alone. In one case, a child was restrained on a booster seat by the centre rear lap belt alone. The soft and highly compressible nature of the booster seat allowed the child to swing far forward and downwards, with head contact towards the front end of the console between the front seats. The tension/distraction of the child's neck, together with the head contact, resulted in fatal fracture-dislocation at two places in the child's cervical spine.

However, other children escaped significant injury despite being involved in very violent crashes. For example, a three-year-old girl was in the left rear position of a 1982 Daihatsu Charade on a soft chaise booster. The car came into frontal impact with an out-of-control oncoming (larger) Toyota on a straight country highway, at a calculated ΔV for the Charade of over 70 km/h. Damage was very extensive, with frontal crush extending back to the A pillar. Both adult front occupants were killed, but the child suffered only superficial head injury and no other soft tissue injuries.

ADULT SEAT BELTS

Lap/sash belts were shown to provide good protection for children, even in high-speed crashes. The main disadvantage of lap/sash belts is that at present they are only available for children sitting in outboard positions, where they are vulnerable to injury from intrusion and contact with the vehicle interior. Children (and adults) would be much safer if they could use lap/sash belts in centre seats, but at present in the vast majority of cars the only restraint available in centre seats is the inadequate lap-only belt.

The ages of the 121 children using adult lap/sash belts ranged from one year to 14 (the sample maximum), with a mean age of nine. Of the 121, 21 (17.4%) were aged five years or less, and would probably have been better served by a child restraint or a booster seat in combination with the adult belt.

Six (5.0%) of the children using available lap/sash belts were killed, 21 (17.4%) suffered injuries with a maximum AIS of 2-4, and the majority (94, 77.7%) had injuries of AIS 1 or were uninjured. Although few of the children in the study for whom only a lap/sash belt was available rode unrestrained, their chance of death or serious injury was much higher.

The youngest child to be killed when wearing a lap/sash seat belt was riding in the front seat of a 1982 Toyota Cressida that ran heavily into the side of an oncoming out-of-control Sigma on a country road, and after the crash ended up on its side. The child was a boy aged three years and eleven months. The ΔV was some 65 to 70 km/h. The child suffered maximum internal thoracic and abdominal injuries, plus a fractured cervical spine at C1/C2. The female driver of the car was also fatally injured, with a fractured skull and internal abdominal injuries. The crash was survivable in the absence of contact with internal surfaces, as shown by the fact that a restrained five-year-old girl in the rear left seat suffered only minor concussion and belt bruising, and a nine-year-old girl in the right rear seat received only belt bruises. This crash was the only one in which a child was killed in a frontal crash while wearing an adult three-point belt.

Although there is still some concern about small children using adult restraints, this study has confirmed earlier findings that children - even very small ones - do surprisingly well in severe crashes when using lap/sash seat belts. As was the case for child restraints, neck injury was not found to be a problem. Adult lap/sash belts do not offer any special threat to children, and children of any age for whom a dedicated child restraint is available must use an adult belt, preferably a three-point lap/sash belt in a rear seat.

The prime cause of injury among children restrained by a adult three-point belts was contact with the interior surfaces of the car, often in association with intrusion.

Although the use of lap-only belts prevented many children in our sample from more serious injury, the evidence of this study is that the lap belt is an incomplete restraint, to be used only when no better system is available. There was a significantly greater incidence of belt-induced abdominal injury among lap-belt wearers than lap/sash belt wearers. The movement of some manufacturers, including major Australian ones, away from the use of centre lap belts and towards lap/sash belts is to be commended.

UNRESTRAINED CHILDREN

There were 19 children in the study who were known not to have been restrained at all in the crash. Five of these children were fatally injured, a far higher proportion than among the restrained children. In fact, as might be expected, the risk of a child coming into the study with a serious (AIS >2) injury was much greater if unrestrained.

While observation in any city street shows that children often ride in the arms of adults, the number of such children in the present sample who received serious - including fatal - injuries while being held this way is still of great concern. There were six definite cases of this occurrence, and one doubtful but probable. All were crashes in which a properly restrained child would probably have escaped injury.

MISUSED RESTRAINTS

There were seven cases of serious misuse of a child restraint. Six of these were associated with poor fitting and/or use of a forward-facing child seat with harness (Type B), and the others were a baby capsule and a booster seat. The numbers are small, but these figures indicate that among all Type B child seats coming into the study, 16% (six out of 37) of cases were associated with misuse, as were one out of six capsule-restrained cases, and one out of 24 booster seat cases.

In particular, all five cases of misuse of a Type B restraint - among which four were associated with injury or death - included failure to fasten the top tether.

THE VEHICLES

For some cars, it had clearly been more difficult to fit restraints than others, and the newer vehicles are much better in this regard than the older. A few of the older cars had manually-adjustable (non-retractable) seat belts, and in a handful of cases the looseness of the belt had probably increased the severity of injury. The fact that most centre lap belts are manually adjustable is a matter of concern.

The most striking feature of the vehicles in the sample was the high proportion of cases contributed by crashes involving four-wheel drive and multi-passenger vehicles. Clearly, these were being used for their intended purpose: namely, to carry many people - including children - at a time. The effect, however, is that when one of these vehicles is involved in a crash, many people are simultaneously exposed to the risk of injury. The numbers are small, but a higher proportion of crashes involving these vehicles included rollover than for the sample as a whole, and rollover added to the risk of injury for both restrained and unrestrained children. Because of the relationship of centre of gravity to track width, many vehicles of this configuration are known to have a relatively high propensity to roll, and it is therefore even more essential that occupants, including children, are offered maximum protection within them.

CONCLUSIONS

One of the main objectives of this study was to determine whether there had arisen in recent years any substantial or common problems with child restraints as approved by Standards Australia, given a much higher rate of use in recent years, the evolution of child restraint design, and the mandating of anchorage points for top tethers in Australian cars.

The indications are that this has not been the case. The vast majority of children in the study who were restrained in child restraints suffered only trivial or minor injury. Several children restrained in child seats, booster seats and adult belts rode out high-speed frontal crashes without any injury. Indeed, this study has confirmed that a child restraint is an exceedingly effective piece of safety equipment, and that the human child is a very resilient animal.

Present data indicate that the main limitations of child restraints are analogous to those of adult seat belts, namely that in side impacts with intrusion they provide not as good protection as in frontal impacts and that in severe crashes they still allow contact with injurious parts of the car interior. Improper installation and use remains a problem.

Otherwise, children in child restraints or lap/sash belts are most likely to be injured by invasion of their space by collapsing seat backs, flying glass and other such mechanisms. The only injuries caused by deceleration alone are likely to be limited to bruising and abrasion from loads imparted from harness and seat-belt webbing, and some minor internal injuries.

1 INTRODUCTION

BACKGROUND TO STUDY

For children, accidents have taken over from infectious disease as the most important single cause of death. Among those accidents, injury resulting from road crashes is a major component. In turn, among road accident victims a large proportion are children injured as the occupants of motor vehicles.

In New South Wales in 1992, 296 (38%) of the 781 children aged 16 years or under who were seriously injured in road accidents received their injuries as the occupants of passenger cars. For those aged four years or less, the figure was 50%. Among those killed on the roads, 27 (48%) of the 56 aged 16 years or under died as car occupants, as did seven of the nine children aged four years or less (Road Safety Bureau, 1993).
The situation is of the same order of magnitude in the world's most motorised countries. In 1982, among a selection of developed nations, between 7% and 41% of the children killed in road traffic accidents were the occupants of cars (Department of Transportation, 1986).

Australia has a well-established Australian Standard for child restraints, a unique Australian Design Rule regarding fitment of child restraints to motor vehicles, and a high rate of use of restraints for children following the introduction of mandatory-use regulations. The efficiency of a restraint system at the community level is a function of the usage rate and the effectiveness of individual restraints in preventing injury. Usage rates in Australia - of both child restraints and adult belts - are very high (see the next section), and thus improvements must be found in improving effectiveness. Because children are still being injured and killed as the passengers of cars that have been involved in crashes it is therefore important clearly to understand how this is happening, to determine whether there are any deficiencies in the performance of safety equipment or the way that it is used and, if so, what measures might be taken to correct such deficiencies.

It is also important to investigate the limits of performance of safety equipment such as seat belts and child restraints, to see how injuries are being prevented in severe crashes and how standards for performance and tolerance may be defined.

Accordingly, the Child Accident Prevention Foundation of Australia (CAPFA), New South Wales Division, throughout calendar year 1993 conducted a research project with the working title "*In-depth Study of Crashes Where Child Car Occupants are Injured*". The study was funded by the Motor Accidents Authority of NSW (the MAA).

Study aims

The project was designed to collect information on the injuries - including minor ones - sustained by children aged 14 years or under who were involved (as passengers in motor vehicles) in a road accident. This age division was chosen because by that stage of life virtually all children are of such size, mass and physical development that to all intents and purposes they can be regarded as adults for the purpose of occupant protection.

This objective included the following considerations:

- to study injuries that occur to children despite the use of different kinds of restraint;
- to estimate, by comparison, the relative effectiveness of different kinds of restraints used by children (including adult belts);
- to study injuries suffered by children not using restraints of any kind;
- to describe the effects in crashes of misuse and poor fitment of child restraints, where that was shown to occur;
- to study survival and injury mitigation in severe crashes.

It was not intended that these objectives would be met by "statistical" means, because the necessary limitation of numbers and sampling constraints would prevent this, but rather that answers would be sought through examination of a selection of crashes involving children. In-depth crash investigation studies of this kind provide important indications and help to build hypotheses that require further analysis.

Report structure

The latter part of this report describes the methods used for study and analysis, sets out and analyses the results, discusses the findings and reaches some conclusions.

First, however, in the following three sections of this report the various types of child restraint are described, the development and design of child restraints outlined, and the literature on child restraint effectiveness is reviewed in the context of what is known about the biomechanics of child injury and child protection. It is in the context of what is already known about child protection that the results of this research should be considered.

2 CHILD RESTRAINT DESIGN AND USE

TYPES OF CHILD RESTRAINT

The type of restraint system that will be most appropriate for the protection of a given child in a given vehicle will vary according to the size of the child, the direction the child is facing when seated in the restraint, and the configuration of the adult seat belts fitted to the vehicle in the different seats.

Requirements for child restraints in Australia (and New Zealand) are specified by Standards Australia in Australian Standard AS 1754-1991/NZS 5411:1991 (1991). The scope of the standard embraces devices intended for passenger cars and their derivatives, although they may have application to other types of vehicle (such as aircraft). The standard does not cover child seats and restraints that are an integrated feature of a new vehicle, and it does not cover requirements for seat belts installed in new vehicles (which are covered by Australian Design Rules).

The standard does cover many different kinds of child restraint, including some that are rarely encountered in Australia. Standards Australia requires designation of child restraints according to the type of each model, into the following groups:

> ***Type A1***: rearward-facing enclosing restraint, suitable for children whose mass is up to 9 kg, and corresponding supine length is up to 700 mm.
>
> ***Type A2***: transversely installed enclosing restraint, suitable for children whose mass is up to 9 kg, and corresponding supine length is up to 700 mm.
>
> ***Type B***: forward-facing chair with harness, suitable for children whose mass is within the range 8 kg to 18 kg.
>
> ***Type C1***: forward-facing harness without chair, not incorporating an adult seat belt; suitable for children whose mass is within the range 14 kg to 32 kg.
>
> ***Type C2***: forward-facing harness without chair, incorporating a lap belt; suitable for children whose mass is within the range 14 kg to 32 kg.

Type D: rearward-facing chair with harness, suitable for children whose mass is within the range 8 kg to 18 kg.

Type E: a restraint consisting of a cushion, chaise or converter used in conjunction with an adult lap-sash seat belt, or Type C1 or Type C2 child restraint; suitable for children whose mass is within the range 14 kg to 32 kg.

Most child restraints are anchored to the vehicle by means of the seat belt, and the child is then secured into the child restraint by means of a harness or other restraining device that is part of the restraint.

These various types of child restraint depend for their effectiveness on different mechanisms, as follows.

Restraints for infants

There are two kinds of restraints designed for infants. According to the above categorisation, they are defined as either Type A1 or A2 in Australia. About 6% of children in New South Wales are restrained in this way (Road Safety Bureau, 1994).

The Type A1 restraint, for infants under 9 kg, is a reclined capsular seat (often referred to as an "infant capsule") that holds its occupant facing the rear of the vehicle. It is held in place by the vehicle's seat belt and a top tether strap connecting with a special mounting point in the vehicle. The child is secured by a body band or harness within the restraint.

In a frontal crash the forces are applied to the body through the child's back, so that the loads are well distributed and the head is further restrained by the seat. In an off-centre crash the restraint tends to swivel towards the direction of impact and thus provide protection. In rear impacts and rollovers, the body band or harness holds the child within the seat. In Australia, where the top tether strap is a unique requirement, it is essential that it be fastened. Otherwise, the restraint will rotate in a crash and the child can be ejected from it. As will be seen in the results section, several severe injuries occurred to children using restraints for which the top tether was not fastened.

When properly used, these rear-facing infant restraints have been shown in the United States to be very effective in real crashes (Melvin *et al*, 1980). However, many of those people who install and use these seats do not understand how they are supposed to work, and will sometimes install them facing forward. Weber and Melvin (1983) showed in an American study that if the seats are installed the wrong way round there is a risk of serious injury from contact with the vehicle seat belt, which is designed to hold the restraint - not the infant - in place.

Ejection is also facilitated if the easy-to-use bodyband, which is fastened by heavy-duty "Velcro", is too loosely adjusted, is fastened over thick clothing, or if the Velcro is clogged with matted cloth fibres that compromise the firmness of its fastening. There have been several narrative reports of ejection from infant capsules with bodybands, and recent amendments to the Australian Standard in effect mandate the use of webbing harnesses, even though these are harder to use and adjust. There is one case in the present study in which the child was probably ejected from a capsule, but as will be described it is likely that the restraint was improperly installed and used.

Rear-facing infant restraints can be used both in the front and the rear of the car, although in practice in Australia the need for a top tether demands their use in the rear.

One problem is that parents sometimes prefer to be able to see their infants at all times, and therefore these seats are often placed in the front of the vehicle in the United States and Europe. The American Academy of Pediatrics has specifically recommended that premature infants be placed in a seat location "that allows for observation by an adult during travel". However, the placement of rear-facing child seats in the front position is incompatible with the use of passenger-side air bags in the vehicle, and with the inevitable increase in air bag fitment over the next few years this placement of the child restraint cannot be recommended. New cars in Europe and the United States are soon to be required to have warnings specifically addressed to this practice.[1]

The other type of infant restraint used in Australia, Type A2, is the "bassinet" or carry-cot style, the first kind of restraint to be introduced for the protection of infants in the Australian market. This type allows the child to lie flat on the back seat of the vehicle, within the restraint, and at right angles to the direction of vehicle travel. The child's head should be placed as near as possible to the centre of the vehicle.

In a frontal impact this restraint is designed to swing upwards and forwards. This ensures that crash loads are transmitted along the length of the infant's body, and additional straps or a body band help to contain the child within the restraint during a crash involving vertical movements or rollover. Again, the use

1 [1] The interaction between airbags and child restraints is discussed later in this report.

of a top tether strap is essential to the correct performance of the restraint. Individual crashes have provided guidance for manufacturers and standards-setting authorities for improvement of this kind of restraint, but these data are at present rather limited. No cases appeared in the present study, probably because these restraints are currently not numerous in the marketplace, the capsule style now being far more popular.

Restraints for older children

Forward-facing child seats

The dedicated child restraint that has been on the world market for the longest time (starting with the Kangol seat in Britain in about 1963) is the forward-facing child safety seat designated "Type B" by Standards Australia. These restraints are suitable for children aged from about six months to about five years. As a general guide, a child can use one of these seats from about the time it can sit up and support its own head. Several are now available in Australia. They are approved for installation in various ways but mainly in combination with the car's retractable lap/sash seat belt or centre-position lap-only belt, plus the mandatory top tether strap. About 28% of children restrained in New South Wales are using child seats (Road Safety Bureau, 1994).

The design of harnesses, whether incorporated as part of child restraint seats or for use on their own, has varied over the years. Most harnesses have two shoulder straps, two lap straps and a single crutch strap, the purpose of which is to hold the lap straps in the correct position low down over the child's pelvis. These have always been rather complicated systems to fit around an uncooperative child, and many child restraints in Europe do not have crutch straps. However, Conry and Hall (1987), Lowne *et al* (1988) and Rattenbury and Gloyns (1993) have all confirmed that children are susceptible to "submarining" under the lap belt if a crutch strap is not fitted and used.

American and Japanese manufacturers have at various times designed replacements for the harness, including padded tray-like structures or curved abdominal shields, and flat shields mounted on solid stalks. However, although crash data have not revealed a high incidence of injury associated with these systems, laboratory evidence and much expert opinion leads to the view that they can be injurious for children in several crash configurations, especially in off-centre impacts. Because solid shields cannot be applied tightly to the child they do not provide good ride-down in a crash. In severe frontal crashes the kinematics lay the child open to a high risk of abdominal and spinal injury.

Convertible restraints

Some restraints in Australia, and several in the United States, are designed to be used rearwards facing when the child is an infant and forward facing when the child grows: so-called "convertible" restraints.

Instructions provided with these seats provide guidance on when the child becomes too heavy to use the seat as an infant restraint, and when it should be used as a restraint for older children. The requirement of Standards Australia is that when the child weighs between eight and nine kilograms, typically around six months of age, the restraint should be converted from rear-facing to front-facing.

Rear-facing restraints offer more protection to the neck of the child, but at just what age and size the child is old enough and strong enough to reasonably withstand forward-facing crash forces is still a matter of debate. It is a matter specifically addressed in the present study. In the United States convertible seats are used rear-facing up to about one year of age.

Child harnesses

Child harnesses intended for use without a child seat (Types C1 and C2) are all of similar design, varying only in the incorporation of the vehicle's own seat belt. They are normally suitable for children aged from about one year of age to about ten years. The Roads and Traffic Authority of NSW has recommended that as a general guide child seats are to be preferred for children up to about five years of age, after which they should use lap/sash seat belts with booster cushions (Type E) (Traffic Authority of NSW, 1988). Sash guides may be necessary to improve the way the sash part of the belt lies across the child's front. However, where the need arises for a child below this age to move out of a child seat, then a correctly adjusted harness may be superior to an adult seat belt as it provides better lateral support for the upper torso. The lap belt should be firmly adjusted across the thighs before slack is removed from the shoulder straps, otherwise the shoulder straps may pull the lap belt up into the abdominal region.

Fewer than 1% of children are now using child harnesses in New South Wales (Road Safety Bureau, 1994).

Rearward-facing child seats

Type D restraints are rear-facing chairs incorporating a harness, suitable for children up to four or five years of age (18 kg; 40 lb). They are very popular in Sweden, where studies have shown extremely low injury and death rates among users of these rear-facing restraints (Carlsson *et al*, 1989, 1991).

Laboratory work and field investigations have shown that loads are better distributed and accelerations are lower with rearward facing seats than forward facing child restraints (Janssen *et al*, 1991; Kamren *et al*, 1993). In Europe there is encouragement for the extension of rear-facing restraint use beyond the age of 18 months by possible changes in weight classes for the various standards. Because of the way they are fitted in the car, these restraints are not permissible under United States or Canadian regulations, although efforts are under way to ease any such restrictions.

Although rearward facing seats appear generally to provide better protection for children, there are many factors which go towards curbing their widespread use. Carlsson *et al* (1991), strong protagonists of rear-facing seats, have surveyed parents with children so restrained. Problems included children who will not sit still, cannot sleep, cannot see out, who undo the belts, and become sick. From a purely protective point of view, *all* rearward facing passengers - whether they are in passenger cars, trains or aircraft - fare better in a crash, all else being equal, than those facing forwards. Yet, because most people prefer to face forwards, it is manifest that crash protection is far from being the only criterion for people in choosing which way to face when travelling. Whether the problems found in Carlsson's survey would be greater or lesser with forward-facing child restraints is not known.

Booster seats

Booster seats and cushions provide a transition for children between the use of child restraint seats and adult seat belts. They were introduced into the Australian Standard in 1978 following the introduction of regulations making it clear that adult seat belts were suitable for use by children aged from one year onwards.

The concept of booster seats originated in Australia and Sweden at about the same time, the Australian work having been performed at the Traffic Accident Research Unit of the then Department of Motor Transport (Herbert and Cutting, 1978).

Boosters are designed to be used with an adult lap-sash seat belt. Their purpose is to improve the fit of adult belts on children by moving the sash strap away from the neck and improving the geometric placing of the lap belt. They have guides for placement of the lap and sash portions of the vehicle's belt.

Booster seats have been found to work generally very well with a lap and sash seat belt, but should not be used with a lap belt alone because without restraint of the upper torso the body and head of the child will be thrown further in a crash than if the child had been sitting on the seat of the car. (A dramatic example of this mechanism was uncovered in the present study.) Some boosters incorporate seat backs, and are known as "chaises".

A child should use a booster cushion or seat until the body size has grown enough to use an adult seat belt. In a recent survey, about 7% of children in cars were using boosters with a seat belt, and 2% with a child harness.

Integrated seats

An adaptation of the booster concept is now being built into a few passenger cars. In Sweden, the Volvo Company has integrated a child restraint with the centre arm rest in the rear seat (Lundell, 1991). Built-in rearward-facing seats have been developed by the company and by some independent research organisations, but are not currently on the market. The US Chrysler car company has also integrated child safety seats into the rear seats of some of their multipassenger vehicles. In the United States seats of this kind, including stand-alone booster seats, must be labelled as being suitable only for children of over 50 pounds weight (23 kg), equivalent to a seven-year-old or thereabouts, but some new integrated installations are suitable for much smaller children than that.

The development, installation and use of all child restraints in Australia have been greatly aided by the installation of dedicated mountings for a top tether strap on (usually) the parcel shelf of the passenger car, behind the rear seat, or on other suitable structures in cars without passenger shelves. This was standardised and mandated by the introduction of Australian Design Rule ADR 34A. The measure has had a considerable influence on the predominant position of forward-facing seats on the market.

Internationally, the International Standards Organisation (ISO) is developing a concept called "Isofix". This proposal envisages that in all vehicles there will be built in a standard set of hardware that would be compatible with all child restraints (Turbell *et al*, 1993). Several prototypes have been tested for usability and crash performance, and a preliminary specification has been developed. Isofix seats may be of forward-facing or rearward-facing configuration (see Figure 1).

DEVELOPMENT AND STANDARDS

During the early 1970s the then Traffic Accident Research Unit (TARU) of the Department of Motor Transport initiated a program by which all child restraints available in Australia were subjected to a program of dynamic crash simulation studies. In addition, some 139 crashes involving restrained children were studied in the field (Henderson *et al*, 1976).

The crash simulations (Herbert *et al*, 1974) were carried out on a Monterey rebound type "sled" that is still in operation in the Crashlab facility of the Roads and Traffic Authority (RTA) today. The restraints that were tested included those already approved by the Standards Association of Australia (SAA; now Standards Australia), plus a selection of seats that were not so approved. Devices were tested with harness straps located correctly and adjusted in some cases as tightly as was considered to be acceptable. In others, the harnesses were adjusted loosely.

All the restraints approved by the SAA performed well in these tests, as did some overseas restraints which had not been submitted for SAA approval. It was found that when tightly adjusted, all of the SAA approved child restraints kept the head and torso of the dummy within the space that would be available if the restraint had been mounted in the centre rear seat of a large sedan. The hands and feet of the dummy, however, often moved beyond the space typically available in Australian cars. During simulation of side impacts, excursions of the dummy were sufficient, together with excursion of the seat, to have brought the dummy head and torso into contact with the car interior in cases where the restraint had been mounted in the seating position nearest the side of the car impacted.

A series of sled runs were also performed with adult seat belts restraining the child dummies, rather than dedicated child restraints. Two disadvantages appeared in comparison with the SAA approved child restraints. One was that the stiffer webbing in the adult belts resulted in much higher loadings in the shoulder straps. In addition, there was a greater space requirement for the restrained dummy during crash loadings.

There were some problems identified at that time with child harnesses, whether mounted in child seats or otherwise. Adjustments of the webbing were sometimes difficult. Some degree of submarining under the lap portion of the harness was observed several times during crash simulations with dummies. This appeared to be related to the geometry of the harness, and in the case of some child seats to flexibility of the seat cushion and its supporting structure. In some cases, high loads in the crutch strap were recorded when the torso of the dummy came into contact with it. This could be an indication that omission of the strap would have allowed submarining to occur. Submarining appeared to be facilitated by tightening the shoulder straps, which then lifted the lap belt upwards. A tight short crutch strap tended to resist this lifting.

Other sled work reported at this time was directed towards the early development of restraints for babies (Vazey *et al*, 1974). Building on that early work, designs have advanced considerably in the intervening 15 years.

Starting in January 1974, teams from the Traffic Accident Research Unit collected information on real crashes in which children had been restrained in passenger cars. This study was one of three early retrospective investigations and the criteria were as follows:

- a passenger car or car derivative crashed in a specified geographical area;
- the car was towed from the scene;
- it contained at least one person who was aged under eight years and who was restrained by some plausible means.

The driver, and where appropriate other adult occupants of the case vehicles, were interviewed. The case car and child restraints were examined and photographed, and medical and postmortem reports were sought for the case children. The initial sampling plan was to capture all crashes in a defined geographical area. This turned out not to be possible, and by the later part of the study in 1975 a child was far more likely to be included as a "case" if he or she had been carried from the scene in an ambulance. This study was known as "Impact 3" (Vazey, 1977).

A total of 132 crashes satisfied the criteria. In addition, some other crashes were investigated for particular reasons. Many of these crashes were trivial, and because the sample was not in the end (as originally intended) representative of the population of crashes at large, it was decided for the purpose of reporting to exclude those crashes in which damage to the case vehicle did not reach a specified rating. The net result was that 57 crashes were selected, involving 65 case occupants. The first objective of this group was to provide evidence that would address the question posed by Snyder and O'Neill (1975): "Are 1974/1975 automotive belt systems hazardous to children?".

At that time in the United States, and to a considerable extent even now in that country, few children were restrained in adult belts that had shoulder belts incorporated. This is because the vast majority of the American vehicle fleet presently has lap belts in the rear positions, although lap-sash belts have recently been mandated for rear outboard seating positions in new cars.

Snyder and O'Neill had noted that in Australia legislation requiring the use of seat belts did not apply to children under eight years, but they wrongly concluded that the reason was concern for the safety of children using adult belts. In fact, at least in NSW it was for administrative reasons associated with the age of legal responsibility. Nevertheless, there was local concern - as there still is now - that children may be so unsuited to adult belts that they might be better left unrestrained.

However, the conclusion of the TARU study was that in practice children appeared to be afforded good protection by adult lap sash belts, even down to two years of age, as long as the restraint was properly adjusted. At that time few seat belts in the rear positions had automatic locking retractors, whereas modern cars are now so equipped. When firmly restrained in well-adjusted belts, the children were found to withstand crash forces as well or better when wearing adult restraints than adults in the same car, even in crashes of 50 km/h change of velocity (delta-V, or ΔV).

The SAA-approved bucket type child restraints (now referred to as Type B) appeared to perform well in the field, as predicted by the laboratory data. In frontal crashes of sufficient severity even to cause breakage of adult restraints and bring about damage equivalent to or worse than a barrier crash of 50 km/h, no children restrained in these seats were more than trivially injured. The two fatal cases investigated both involved side impact of sufficient severity to intrude into the child and occupants' survival space. In no case was injury inflicted by the child harness itself more than bruising and abrasions. No neck injuries were detected, even in the case of a seven-month old girl only marginally suited to this type of restraint in a violent frontal crash. As will be seen, the present study has confirmed the extreme rarity of neck injury in high-speed collisions in the absence of head contact.

The authors commented that fears expressed from time to time that the child's neck may be placed in special danger in these crashes had not been borne out by their data. They warned, however, that child restraint devices must be used properly to be fully effective. In principle, they suggested, an aim of child restraint design should be that the system cannot be used wrongly even by the incompetent or uncaring.

Child harnesses designed for children too large for special child seats appeared to offer good protection in frontal crashes. It was not possible to say whether the children were better protected than if adult lap/sash belts had been used.

Bassinets (carry-cots) were used to protect infants in those days, and they appeared to protect the children lying in them surprisingly well. None of the six children in the series were ejected.

This first study of children in cars was followed later by another using the same methodology, and reported by Corben and Herbert (1981). The follow-up study was aimed at identifying any shortcomings in SAA-approved child restraints and adult seat belts in Australian cars. In particular, it was hoped that experience would be obtained of the performance of child restraints approved to the then relatively new Australian Standard AS 1754-1975. For the first time, this included requirements for dynamic testing.

This second study, which dealt with selected crashes occurring between November 1977 and May 1978, was known as "Impact 7". It included 223 crashes. Again, the sampling plan defined "cases" as being children under the age of eight years transported from the scene by ambulance. Some special investigations were also made of fatal accidents. The in-depth investigations consisted of the 35 crashes in which at least one of the under eight-year old children was wearing an adult seat belt or a child restraint approved by the SAA.

Twenty of the children were in child seats, and for nearly all of those the protection was very good. The only fatality resulted when a child seat was broken by luggage in the rear luggage compartment and the child's head contacted the back of the driver's seat. There were other non-fatal cases of head injury from contact with the adjacent parts of the car. There were also some cases of bony and soft tissue injury through loading of the body parts by the restraint. Intrusion of the vehicle sides and loose mounting of the child restraints were identified as factors contributing to injury.

Five children had worn lap/sash seat belts with emergency locking retractors and 24 wore manually adjustable lap/sash belts. Eight were wearing lap belts alone. Again, serious injuries were related to intrusion of the vehicle structure and to loose wearing of the restraint system. Some injuries were also associated with children lying down in loose seat belts or otherwise not wearing them in an appropriate manner. Two of the eight children who were thought to have worn lap belts were killed. One was apparently ejected from the centre rear lap belt during a rollover collision. Another child who was placed on cushions within the lap belt received a fractured cervical spine and head injuries, possibly from contact with the back of the driver's seat. This was a severe collision in which the two restrained adults in the front seats were killed.

Roads and Traffic Authority (Road Safety Bureau) staff have ever since those early days continued a close involvement with the continuing evolution of child restraints of all kinds, including membership of the Working Group on Child Restraint Systems of the International Standards Organisation (ISO) (Lundell *et al*, 1993).

The present study was designed with the intention of building on this earlier work on New South Wales by using similar methodology but with a larger sample, and adding new techniques for crash reconstruction.

CHILD RESTRAINT USAGE

In all states in Australia there are now laws requiring the use of restraints, including adult belts, for children riding in cars. The details of the regulations differ from state to state. In New South Wales it is an offence to allow a child to travel unrestrained in a motor vehicle when a child restraint bearing the Standards Australia certification mark, or an adult seat belt, is available. All children under the age of 12 months travelling in vehicles fitted with child restraint anchorage points must be provided with approved safety restraints suitable for their age. Further, it is an offence for children to be unrestrained in a front seat when a rear seating position is free.

In New South Wales, the use of restraints by children has gradually increased since regular measurements by roadside observation began. In 1982, 54% of the children riding in front seats were restrained, and 52% in the rear. By 1993 this had grown statewide to 90% in the front and 87% in the rear (Road Safety Bureau, 1994). In rear seats, children are more likely to be restrained than adults, for whom the use rate is 80%.

In this roadside survey data, among restrained children 51% were wearing adult belts, 30.8% using child seats, and 10.2% boosters. In the present study, 68.4% were using lap/sash or lap belts (this differentiation was not made in the roadside studies), 18.4% child seats, and 10.5% boosters. Thus, in the study there were relatively more seat-belt wearers, and fewer child seat users. Suspected or proven injury was the reason for entry into the study, so it is open to speculation whether this difference between figures for different restraints reflects the superior effectiveness of child seats. However, not enough is known about the two populations from which the figures are drawn to permit such speculation.

Where restraints were available, the above NSW survey data show that the usage rate of infant restraints in 1993 was 98.7%, child seats 96.4%, boosters 96.6%, and adult belts by children 83.2%.

In Melbourne, where figures are also available for wearing rates by age, 1982 observations showed 75-80% of 0-13 year old children were restrained in front seats. In the rear seats, 97% of the 0-7 year olds were restrained, and 75% of the 8-13 year olds. These figures have also increased, so that in 1990 nearly 95% of children in the front were restrained. In the rear, restraint use was about 10% lower.

MISUSE OF CHILD RESTRAINTS

Several authors have documented how easy it is to install and use forward-facing child restraints incorrectly. Dangerous practices that have been observed include not using the seat harness straps, leaving either the seat belt mounting straps or the harness straps very loose, having the crutch straps too long, placing the shoulder straps under the arm, and applying the vehicle seat belts wrongly to the child's seat. In Australia, another method of misuse is that the top tether strap may be left unfastened or be fastened wrongly; cases where this resulted in injury are documented in the present study. All these different kinds of misuse can lead to a significantly higher risk of injury for the children.

Over the years many problems of compatibility between vehicles and child restraints have emerged. In 1986 the National Roads and Motorists Association (NRMA) reported a number of installation problems discovered during systematic inspections of motor vehicles or reported by members of the public. Booth (1988) reported a follow-up investigation of 44 new vehicle models that were inspected, having been manufactured between 1986 and 1987. An earlier 1986 study had shown that child restraint anchorage points mounted behind the rear seats were sunk into the trim of the motor vehicle. In these cases child restraints could not be installed correctly without the use of spacers at the anchor point locations. In this follow-up study many vehicles still had recessed child restraint anchorage points, and neither vehicle manufacturers nor child restraint manufacturers were supplying spacers to ease fitment. Several vehicles also required extension straps for the top tether strap in order to ensure proper installation. Extension straps are quite easily available, but there are ample data to show that if a system can be installed wrongly then sooner or later it will be. Child restraint manufacturers are increasingly noting this potential problem in their installation instructions. The problem is especially prevalent in hatchback vehicles with no solid vehicle structure immediately behind the back seat.

Booth also pointed to the unavailability of child restraint anchorage points in several types of vehicles that carry passengers. These include four-wheel drive vehicles that are not required by law to have anchorages for upper tether straps. Aftermarket supply and fitment of a child restraint anchorage bar is possible, and an example appeared as a case vehicle in the present study.

Some child seats are still difficult to install because of problems with the geometry of the vehicle seat belts, although this problem seems to be decreasing. In some cases there is an inadequate angle between the child restraint top tether strap and the anchorage, which places unacceptable loads on the anchorage system. Further, in some earlier vehicles hardware fouled the strap. In a few vehicles it is next to impossible to fit a child restraint at all, and this has necessitated some exemptions in the NSW child restraint regulations.

The recent roadside survey for the Road Safety Bureau of the NSW RTA (Road Safety Bureau, 1994) indicated that 4.6% of infant restraints were being used "incorrectly", as were 7.9% of child seats. These figures are much lower than overseas studies have documented.

For example, in two parts of Sweden, some 41% and 65% respectively of the child restraints investigated were found to be misused. The most common form of misuse of rearward facing child seats was that it was used facing the wrong direction. The most common type of misuse associated with forward-facing booster cushions and child restraint seats was that the guide for the lap part of the seat belt was not in use. This would mean that the child was not properly anchored to the restraint system and the restraint system was not properly anchored to the car. Sled testing confirmed that if forward-facing booster cushions and child seats are tested without using guides for the seat belts, the restraints slide forward under the child while the lap part of the seat belt loads the abdominal region.

As an interesting light on the above figures for misuse in Sweden, Carlsson *et al* (1991) found that nearly all parents who *did not* have a child seat thought that it was important that it was easy to install, whereas those who *did* have a child seat rarely encountered problems with installation. However, it is apparent that many still get it wrong, knowingly or otherwise. Cynecki and Goryl (1984) interviewed parents who had been observed misusing child restraints. They found that 70-90% of the parents had known what the correct actions were, but had chosen not to take them.

Child restraint misuse is also now clearly identified as a serious problem in the United States (Petrucelli, 1989). Designers and manufacturers have responded by improving their designs and labelling in order to discourage misuse or make it impossible. Analytical approaches have been developed, and Czernakowski and Muller (1991) have used systems analysis to predict the extent to which child restraint systems can be misused and thus predict and subsequently reduce the risk of such misuse.

Evidence of misuse was found in the present study, but it was not found that injuries were associated with a high degree of "minor" misuse such as slightly loose harness straps. However, as will be described in more detail, injuries were associated with non-use of the top tether, and with booster seats used incorrectly with a lap belt alone. Injuries were also associated with installations that failed to use all necessary parts of the vehicle's seat belt for installation of a child restraint. Out of 37 children using forward-facing child seats and coming into the study, six (16%) were associated with misuse, in five cases misuse that directly contributed to injury or death.

THE USE OF ADULT SEAT BELTS BY CHILDREN

Seat belts were designed for adults and under most international regulations are tested for compliance using adult dummies. However, a very high proportion of the occupants of vehicles, especially in the rear seats, are children. For these young occupants adult seat belts were not designed, and child size is often only poorly compatible with the location of the seat belt anchorages, the buckle size and position, and sometimes the seat belt retractor.

However, as long as children can sit up by themselves there is nothing inherently wrong with their using adult seat belts, and it is certainly better than no restraint at all. For them to use an adult belt is simply to place their level of protection at the lower end of a spectrum of safety performance, at the higher end of which would be a restraint especially tailored to the child and to the vehicle.

As far as possible, the lap belt (whether alone or in combination with a sash portion) should be placed low down on the pelvis of the child, and any sash belt should lie as far away from the neck as possible. This usually means that the child will have to sit near the buckle. It does not seem that sash belts pose a threat to the neck as long as they are simply touching the side of it (Corben and Herbert, 1981). It is definitely never desirable to route the sash portion of the belt behind the child or under the arm.

Several cases of survival without injury among small children using adult belts in violent crashes are documented in the present report.

THE ADULT'S LAP

While the use of restraints is high in Australia some children, especially very small ones, travel on the laps of adults while being held in the arms. Cases of severe injury and death to the child following this practice ere included in this study. Agran *et al* (1991), in the United States, studied the conditions under which children travel on adults' laps. The extent to which injuries would be reduced if these children were restrained in child safety seats was also examined, through study of a population of injured children. Only children of under one year of age were included, and information was obtained from medical records and parent interviews.

Agran *et al* found that parents frequently placed the child on the lap in order to attend to a child's needs, feed the child, or because they felt that the child was more secure. However, these authors also found that a high proportion of these children received serious injuries, including head and brain injury, whereas if they had been restrained in child safety seats there would be an expected 26% reduction in overall injury, a 75% reduction in hospitalisation and a 69% reduction in intracranial injury.

3 THE BIOMECHANICS OF CHILD OCCUPANT INJURY

THE PRINCIPLES OF CHILD RESTRAINT

The principles of restraint design for children were described by Herbert *et al* (1974a, 1974b), and they are still appropriate today. Within the spectrum of "survivable" crashes the following should apply:

- the child should be retained within the vehicle;

- the child's head and torso should be prevented from hitting the interior of the car;

- the restraining forces applied to the child in forward-facing devices should be fairly uniformly distributed between the chest and pelvis without heavy loading of other parts of the body.

There are many anatomical and physiological differences between adults and children (Herbert *et al*, 1974; Society of Automotive Engineers, 1980). The average weights and heights of children range very widely as they grow from birth through to the early teens. In addition, there are great differences between adults and children in the relative sizes of the body segments. For example, the length of the head of a new-born child is one quarter of the total body length, whereas in an adult the head is only one seventh of the total length.

The size and shape of the bones of the skull are different in a small child from those in an adult. The same is true for the chest cage. In the abdominal area, the pelvic bones provide less protection for the abdominal organs, and the child pelvis lacks the anterior superior iliac spine that is so important for the location of an adult lap belt on the body.

The centre of gravity of the child body is higher than for an adult, so that the kinematics of the body in a crash will vary depending upon age. The physical structure of the child's body reacts to impact forces in a different way to an adult, which is in large part due to the different reaction of the child's bones to impact loadings. For instance, the skull of the child has been shown to be far less resistant to bending stresses than the bones of a fully developed adult skull (Corner *et al*, 1987).

It has long been known that the risk of death and severe injury increases with increasing age (Baker *et al*, 1984). More recently, Evans (1988) has used a well-controlled method to quantify how death and injury risk is related to age. He confirmed that once the age exceeds about 20 years, the risk of dying as a result of a given severity of injury grows at an approximately uniform rate until at the age of 70 the risk of dying is about three times what it is at the age of 20. Evans also showed, however, an increased risk of dying among those aged under 10 years. This risk rises with *decreasing* age, until in the first few months of life the risk of dying in a given impact is about the same as it is at the age of 45 for females and 70 for males. Schmidt (1979) and Mattern *et al* (1979) have also commented on the intolerance of a child's body to high impact forces in comparison to that of an adult.

However, contrary to the above conclusions, when properly restrained children appear to be able to withstand a crash at a given impact speed better than adults in the same vehicle, and this supposition was supported by the results presented in this report. This is partly because the force on the body restrained by a seat belt is proportional to the mass of that body. For example a man weighing 82 kg in a crash resulting in a deceleration of 15 g will load the seat belt with a force of 12 kN. A 9 kg child in the same crash however, will experience a force of 1.3 kN distributed through the restraint system.

Sturtz (1980) performed a series of laboratory crash tests correlating child dummy measurements with actual crash injuries. He concluded that the data were insufficient to establish definite tolerance limits, and that there were virtually no data for the abdominal and pelvic regions of the child. He did not discuss the neck. He concluded that the tolerance to deceleration of the chest of the child was similar to that of adults, but he proposed criteria for head injury for children (using a 6 year-old size dummy) that would be considerably below the threshold for adult dummies.

Dejeammes *et al* (1984) correlated crash tests with child cadavers with the results of tests with child dummies. They concluded that the tolerance to head injury of the child was higher than for adults, but they did not include accelerations occurring on head contact whereas Sturtz (1980) did. As the stiffness of the head of the child is lower than for an adult, there will be a lower tolerance to contact accelerations including those generated by an air bag inflating into the head of an out-of-position child.

The main concern about injuries to restrained children is the load placed on the cervical spine in a crash by the relatively heavy head of the child (Fuchs *et al*., 1989). This concern is behind attempts by authorities in some countries to increase the use of rearward facing child restraints. Planath *et al* reconstructed (using dummies) accidents reported by Lowne *et al* (1988), and with other data suggested guidelines for neck injury criteria. They concluded that neck flexion in the forward-facing child could cause injury at quite low levels of force.

A basic problem has been that most predictions for childhood impact injury are based on adult data, and the dummies used to simulate children have not been high in validity ("biofidelity"). There is a current need for the determination of threshold figures for neck injury in forward-facing restraints, and for more correlation of crash and laboratory data. There is also the problem that much real-world biomechanical data are generated from studies of *injured* human beings, including children. If a safety device is working well, the effect is that the "injuries" that are prevented are never seen, leaving for observation only the generally severe injuries sustained in the more violent events from which no system can provide adequate protection. To obtain a complete picture, therefore, there is also a need to study crashes in which children escaped with minor or no injury from crashes in which they were exposed to heavy impact loadings.

The biokinetics of child restraint

Restraining vehicle occupants as a means of crash protection has been known to be effective for decades. However, it was not until 1968 that Bohlin (1968), using the large Volvo database, published good numerical data that established the extent of protection. His study also confirmed earlier conclusions of those who had studied crashes in the field in depth that the three-point (lap plus diagonal sash) type of seat belt was the most effective compromise between safety and convenience for adults.

When a car crashes, the occupants of the vehicle continue moving at the speed of the vehicle immediately before impact. If unrestrained, these occupants will hit the decelerating interior of the vehicle at their pre-crash speed, or they may be ejected from within the vehicle and collide with the ground or roadside obstacles.

When the same occupants are restrained, however, this "second collision" is between the occupants and the components of the restraint system. The front part of the structure of motor vehicles collapses during impact in a way that - in modern cars - is determined by design engineers. By coming to a stop over a greater distance and longer time than if the vehicle was a completely solid structure, the deceleration of the occupant compartment is lessened. The aim of restraint systems is to tie down the occupants to the occupant compartment so that they can "ride down" the crash in a comparatively gentle way.

When seat belts or other restraint systems are tightly adjusted to the body, the distance for "ride down" is maximised. But the restraints may thus be uncomfortable during normal use. Restraints worn loosely bring the body to an abrupt halt, which can increase the chance of injury to internal organs as they move violently within the body.

The benefits offered by restraint systems can be supplemented by changes to the vehicle's interior structure. Interior surfaces may be made less injurious when forced down upon the occupants at impact, or when the restraint systems allow body movement within them sufficient to permit contact between the occupants and the vehicle's interior. Some protective devices, such as the airbag and seat belt tensioning systems, come into play at the instant of the crash by increasing the effective thickness of the padding of the vehicle interior and improving the operational efficiency of the restraint system.

Part of the compromise faced by the restraint system designer is the need jointly to address the demands of comfort and convenience. These may conflict with the demand for maximum crash performance. In addition, while restraint systems work best by distributing the loadings over as wide an area of the body as possible, in practice the load distribution is limited by practicality, by the need for some body movement within the vehicle, and (particularly for adults) the desire to face forwards. Further, the driver must be free to move the limbs and the head. The effect of all this is to encourage restraint designers to distribute the loads over the strongest parts of the body. These include the bones of the shoulders and the pelvis, and to some extent the thorax.

The compromises are even more telling in the case of child restraint. For children and infants, as already noted bony structures are not well developed and therefore the impact loads must be distributed over wider areas. Some parents may be reluctant to accept rearwards-facing seats in rear seating positions, because they cannot then see the child. Children fidget, and may compromise the efficiency of any kind of restraint, and particularly the more restrictive ones, by moving around to play or interact with other occupants.

When impact loadings on the body are poorly distributed by restraint systems, injuries are more likely to occur. This is especially the case if the restraint system passes loadings to those soft parts of the body that have little or no bony protection.

The CAPFA study: project methodology

4 THE EFFECTIVENESS OF CHILD RESTRAINTS

STATISTICAL ANALYSES

Using mass data, the effectiveness of child restraints was analysed in the United States by Kahane (1986), who found that as long as they were properly used and secured, child restraints reduced the risk of death and serious injury by about 70%. This is a greater amount than the best estimates for average reductions in the risk of death among adult users of lap and lap/sash belts, which are in the order of 50% (Evans, 1986; Partyka, 1988).

In some parts of Europe, and especially Scandinavia, rearwards-facing child seats are strongly favoured, having been made and sold by manufacturers such as Volvo for decades. Generally, rearward-facing seats are only used up to about the age of four years in Sweden. They are undoubtedly effective. Using the Volvo database for analysis, Carlsson *et al* (1991) estimated that the injury-reducing effectiveness of rearwards-facing child restraints was 80-90%, while the effectiveness of forward-facing booster cushion/seats was 30-60%.

Typically, clinical studies are based on groups of individual children and their medical records. These children may or may not have been injured, and outcomes are compared among children using restraints and those who were not. Such studies can also be used to determine deficiencies in restraint performance. However, children who escape injury because of their use of restraints are far less likely to come into these studies than the injured, and thus statistical comparisons between large groups of uninjured and injured are impossible. This is, of course, the case for the present CAPFA study.

In a study that did include uninjured children, Tingvall (1987) studied restraint effectiveness by collecting data on children involved in road traffic accidents as occupants of cars, irrespective of the outcome. Both restrained and unrestrained occupants were included. It was found that the risk of injury to children was strongly linked to the use of restraints. Of those children who were using a rear-facing child restraint 1.2% were injured, while the corresponding proportion of those injured using a forward-facing child seat were 6.9% and those using adult seat belts alone 8.9%. Among unrestrained children 15.6% were injured.

When restraints were used, the injury pattern was different from that in the unrestrained. Injuries to the head and the extremities became relatively less common, and injuries to the neck and abdomen were relatively more common among restrained than among unrestrained children. For unrestrained children in the rear seat the risk of injury was lower in the middle position than for the outboard position, but for restrained children there was no such difference.

The weight of the car in which the children were occupants was found to be related to the risk of injury for restrained children but not for unrestrained. The risk of injury was higher in accidents involving intrusion into the vehicle passenger compartment.

Overall, the conclusion of Tingvall's good study was an estimation that the effectiveness of different restraint systems in Sweden in preventing injury were as follows:

- for rearward facing child restraints 79%;
- forward facing child restraints (including adult seat belts) 36-63%, and for more severe injuries 65-91%;

The number of children receiving severe injuries in rearward facing restraints was too low to permit a statistical analysis of effectiveness.

PATTERNS OF INJURY

Study of the injuries suffered by children who are actually using restraints is of fundamental importance to the reduction of child occupant injury, and this was a primary target of the research reported here. This is because such a high proportion of children riding in cars in Australia are restrained. It is for them that measures to reduce injury must be found.

Agran, Dunkle and Winn (1984) described injury patterns related to the use of various kinds of restraint. The sample consisted of children of under four years of age seen and treated in emergency rooms after involvement in a motor vehicle crash. Most children using child safety seats or adult seat belts, if injured, had sustained minor injuries only. These were mostly contusions, abrasions or lacerations. There were a few who were more seriously injured. It was concluded that injury among children in properly used child safety seats was primarily the result of mechanisms such as flying glass and intrusion of the motor vehicle into the passenger compartment. Improper use of the restraint also contributed to injury among some children using child safety seats. Children injured despite wearing seat belts mostly received their injuries as a result of impact against the dashboard or the back of the front seat.

In a further study of the series reported by Tingvall (1987), injuries in spite of the use of restraints were investigated. Only six of the injured children were sitting in a rearward-facing child seat at the time of the accident, 82 children were restrained in forward-facing child seats, and 149 were restrained only by an adult seat belt. The head was the most common site of injury, with neck and extremity injuries also common. The side structures of the car were the most common source of injury, followed by non-contact injuries and injuries caused by the restraint system. Among children using an adult seat belt alone, the restraint was the cause of most of the injury.

Tingvall reported that according to the Swedish Road Traffic Safety Office only three children restrained by a rearward facing seat had been fatally injured since the beginning of the seventies. One child was fatally burned but otherwise uninjured in a rearward collision. Two children were killed in side collisions of high severity where there was no chance of survival after the accident.

Turning specifically to the use of adult restraints by children, Agran and Winn (1987) studied trauma patterns in motor vehicle collisions among lap belted and lap/sash belted children. There were 229 cases selected, comprising 88 in a lap/sash belt in the front seat and 141 in a lap belt in the back seat. There were no significant differences in injury severity, anatomical site of injury or rate of hospitalisation between those in a lap and those in a lap/sash belt. However, certain patterns and mechanisms of injuries were apparent. Injuries to the head and face were sustained by nearly half of the entire sample. Some 10% of the lap/sash belted and 12% of the lap belted children sustained injuries to the abdomen. Cervical strain injuries were sustained by 21% of the lap/sash belted and 14% of the lap belted children. The most common mechanism of injury was impact against the vehicle interior.

Overall, the conclusion of this paper was that seat belts designed for adults provided reasonable protection for children. In this sample only 12% of the children received more than a minor injury. Despite the doubts held by many people about the wisdom of using lap belts on their own, this study showed no statistically significant differences in injury between those who were lap belted in the back seat and lap/sash belted in the front seat. Neither type of seat belt was preventing strain injuries of the neck. Out of the entire sample, 11% of the seat belted children sustained an injury to the abdominal area. Serious intra-abdominal injuries were less frequent, but were commoner (3%) among lap belted children than those using lap/sash belts (1%). The numbers, however, were very small indeed in these sub-groups.

Campbell (1986) also analysed lap and lap/sash belted occupants, and also reported significant differences in injury between the two systems but only at levels of severe vehicle damage.

That it was difficult for these researchers to enumerate differences between the injury patterns associated with different kinds of restraint is not particularly surprising. Any kind of restraint is much better than no restraint at all, and therefore injuries among restrained people - whether adults or children - are small in number when compared with the total population of injured vehicle occupants. Differences in the effectiveness of various kinds of restraint will only emerge at the severe end of the injury spectrum because minor injuries are prevented by most restraints, whatever their configuration. However, minor injuries can be indicators for the potential of more severe ones. For example, if in average-severity collisions children restrained by a lap belt in the centre rear position consistently hit their heads on the console between the front seats, but without causing severe trauma, it is reasonable to postulate that in a high-speed crash the head will still strike, but with a severity that could cause severe injury that might be prevented by restraint of the upper torso. This pattern of injury was observed on several occasions in the present study.

Agran and Winn (1988) analysed patterns of injury and severity of injury among restrained but injured 4-9 year-old children, looking in particular for evidence of impact sites. All the children in this American series had outgrown child safety seats and had been placed in an adult seat belt system.

It was found for their ample that 85% of the injuries suffered by the children were minor. However, a striking feature of this study was the high proportion of children in all seat locations and impact sites who sustained injury to the head and face: 64%. Among the serious head and facial injuries, 41% of the children were located in outboard seating positions and involved in a lateral impact in the region of the seat with vehicle intrusion. There were few cases of serious injury among those placed in the back seat, and injury in the back outboard positions - even when seated near the point of impact - was from impact against the interior parts of the vehicle rather than from intrusion. Injuries to parts of the body other than the head were uncommon and when they did occur were generally minor contusions and abrasions.

These authors proposed that the major issue of concern is the ability of the head of restrained children to impact against an interior part of the vehicle. When a lap belt alone is used, hyperflexion of the upper torso over the belt can occur. Even when a lap and shoulder belt is used, head contact is still possible. Although when properly used a lap/sash belt does restrict movement of the upper torso, Agran and Winn suggested that this configuration would not be as effective for children as for adults, pointing to the poor development of the anterior superior iliac spine of the pelvis at under 10 years of age, and to the fact that the shoulders of children may not combine well with the shoulder strap of the seat belt.

They also pointed to the several respects in which the anthropomorphic characteristics of a child are markedly different from that of an adult, as shown earlier in this report. The child's sitting height is less than that of the average adult. The centre of gravity, which varies with age, height and weight, is above the level of the lap belt, which alters the fit of the restraint system as compared to the adult. The greater proportion of the body mass above the belt may cause more forward motion, with an increased risk of head impact with interior parts of the vehicle. The combination of a large head and small face seems to predispose children to head and facial injuries. Another anatomical factor relates to where the lap part of the seat belt is mounted in the vehicle. The distance between the anterior superior iliac spines is less than that of an adult, and these are not adequately developed to serve as anchor points for the seat belt until the child is about 10 years old. The degree of protection of the intra-abdominal organs by the thoracic cage is less in young children compared to adults (Burdi *et al*, 1969).

In addition to these anthropometric features, they suggested, children decrease the capacity of the restraint systems to protect them by their moving and wriggling, leaning, sleeping and general child-like behaviour.

In other countries also, researchers have been looking for differences in protection offered by lap belts and lap/sash belts. In Sweden, Krafft *et al* (1990) conducted a prospective study of over 10,000 occupants. The usage rate of seat belts was 95% in the front seats but lower than 40% in the rear. They found that the risk of a child being injured was generally lower than an adult, but most children in the study were sitting in the rear seats. Taking account of that, and the weight of the car, the risk of injury in the front and the rear seats was much the same. The risk reduction due to restraint use in the rear seats was for children more than 50% and 23% for adults. This compared with the rather lower levels of effectiveness shown by Evans' studies in the United States, and these authors suggested that this was because lap belts were much more commonly used in rear seats in the United States than in Sweden.

Also in Sweden, an important study was conducted by Lundell *et al* (1991). They analysed the Volvo accident data base up to 1990 in relation to belt use and the development of the Volvo integrated child restraint system. They concluded that their data supported theoretical arguments to show that the three-point belt provided better protection in a crash than a lap belt alone. They showed that the risk of injury to *unbelted* occupants was greater in the outer position than the centre position. On the other hand, the risk of injury to *belted* passengers is about the same in the outer as in the centre positions. This indicates that the two-point lap belt is not as effective in reducing injury as a three-point belt.

Evans (1991) summarised his work on lap belts in the rear seats using data from the Fatal Accident Reporting System (FARS) in the United States. His combined estimate of effectiveness was 18% ± 9% for the effectiveness of lap belts in preventing deaths among outboard rear occupants. This compares with his estimate of the fatality reduction for lap/sash belts as 40% for drivers and 39% for front seat passengers. Later work by Evans, published in correspondence with the US National Highway Traffic Safety Administration, puts his estimate of lap-belt effectiveness even lower than that and concludes that the main benefit of a lap belt is in preventing ejection.

Injuries caused by restraints

While studies have consistently shown that seat belts of all kinds of configuration provide benefits overall, certain injuries are caused by them. This issue has become a particularly contentious one in the United States, where several manufacturers are now being sued by those plaintiffs who have suffered abdominal and spinal injuries resulting from the use of lap belts in rear seating positions. Only very recently have lap/sash belts been made generally available in American cars in rear outboard seating positions.

Even in Australia lap belts alone are still permissible (and normally fitted except in a few imported luxury models and late-model Australian family cars) in centre seating positions.

Reference has already been made to the opinion of some analysts that the use of some kinds of restraint can increase the risk of neck injury (over other kinds of restraint, it should be emphasised, not over no restraint at all). Agran *et al* (1987) found that there was an increase in neck injuries with increased seat belt use among children, particularly those aged 10-14 years of age. Norin *et al* (1984), using a sample of seat belted children in Sweden, reported a slight increase in minor and moderate neck and chest injuries from the forces of the belt. However, it is to the direct effect of restraints on abdominal injury that most of the literature is addressed.

The most comprehensive recent review of intestinal and lumbar spine injury in children was reported by Newman *et al* (1990). They reviewed all trauma admissions to a children's medical centre in Washington DC over a three-year period. Ten children among the 2,602 blunt trauma admissions to the centre sustained a lap belt injury (10.5% of the 95 children wearing seat belts). Five children suffered a lumbar spine injury only, four suffered a lumbar spine and intestinal injury, and one child suffered an intestinal injury without lumbar spinal involvement. Seat belt bruising was present in all ten children.

These authors listed several factors they considered put children at increased risk of lap belt injury. It was greatest for passengers wearing lap belts only rather than three-point lap sash belts, and lap belts were more common in the rear seats of automobiles where most children ride. Because the National Highway Traffic Safety Administration had recommended that children not use the shoulder belt part of a three-point restraint if it falls across the neck or face, and because there was increased compliance with state seat belt use laws, children were frequently restrained by lap belts designed for adults. They suggested that the increased use of three-point restraints would reduce these injuries.

Another recent study that included children was a comprehensive examination of all patients admitted to a regional trauma centre during the period 1984 to 1988 for treatment of spinal and/or abdominal injuries suffered by motor vehicle occupants involved in a crash (Anderson *et al*, 1991). They found that patients with Chance-type fractures of the lumbar spine were much more likely to be rear seat passengers and to be using a lap belt than were patients with other types of spinal injury.

Patients with injuries to the hollow abdominal organs were also more likely to be rear seat passengers and to be lap belted than were patients with injuries to the spleen, liver, pancreas or kidneys. Nearly two-thirds of the lumbar Chance fractures were associated with injuries to the hollow abdominal organs, including six of the seven children. This increased risk of Chance fractures and injuries to the hollow organs was associated with the increased use of lap belt restraints.

A recent paper by Lane (of the Monash University Accident Research Centre) for the Federal Office of Road Safety (Lane, 1992) pointed to the fact that the lap belts fitted to the centre seats of Australian cars for the past 15 years have come under criticism as threatening injury to children. Reporting on two Melbourne studies, Lane - as part of a comprehensive review - confirmed the association of the seat belt syndrome with lap belt use. Lane refers to a review by Hoy and Cole of the Melbourne Royal Children's Hospital for the period 1984-1989. Of 541 casualties, 29 had belt injuries of the abdomen and of these seven had Chance fractures of the spine. One had a cord injury without radiological abnormality. There was a nearly four-fold increase in cases of seat belt syndrome among children admitted to the Royal Children's Hospital over this nine-year period. Lap belts alone were used by 19 of 28 cases for which the type of restraint was known. For rear seated children (excluding children using child restraints) 19 were in the centre (lap belt) seat and five in outboard seats with lap/sash belts. Lane's data on belt wearing rates in Victoria indicate that there were more child occupants in outboard seats than centre seats, so the above results indicate that there was a pronounced tendency for seat belt injuries to be associated with lap belts.

Lane also extracted additional and hitherto unpublished data from the study of passenger cars and occupant injury reported by Fildes *et al* (1991). This is a sample of occupants in modern passenger cars admitted to hospital after a crash. It appears from Lane's calculations that the relative risk for a lap-belted rear occupant of sustaining a seat belt injury is 3.6 times that for a lap/sash belted occupant.

Lane also used Victorian Transport Accident Commission injury compensation data to estimate the incidence of the seat belt syndrome. Combining these data with wearing survey data, Lane found that the centre seat was shown to be associated with a significantly increased risk of seat belt syndrome. This increase was by factor of two for children and by a factor of almost three for adults. Lane concluded that replacing the lap belt with a lap/sash belt could be expected to eliminate about two-thirds of the belt-related injuries among occupants of the centre rear seat.

5 THE CAPFA STUDY: PROJECT METHODOLOGY

THE SAMPLE

The study was of "child occupants". These were defined as children aged 14 years or under who were occupants of passenger cars or passenger car derivatives involved in a crash of any severity.

The study aim was to include for analysis the following cases:

- all fatally injured child occupants from throughout the state;
- any child occupant involved in a crash in which another occupant was killed anywhere in the state of New South Wales;
- and all child occupants presenting to hospitals accepting trauma patients in the greater metropolitan Sydney area.

Two basic notification procedures were employed, and they are described in more detail below. Broadly, information on fatal crashes was received through existing procedures involving the Roads and Traffic Authority and the police service, and non-fatal injuries were notified by hospital staff and on occasion by ambulance personnel.

Because the intention of the research was to uncover problems and deficiencies, it was never intended to seek out cases where injuries were completely prevented by the use of restraint. This sample is of a subset of "injured" children, not of all children involved in crashes. Nevertheless, many children who attended emergency departments were found to have been injured to a trivial extent only, but had been transported to hospital among others (such as parents) who had been injured, or just because ambulance personnel considered that observation and review by medical personnel was necessary. These cases would normally be recorded in official police and RTA records as having been injured to a "minor" extent, so direct comparison of the present sample with officially-recorded mass data is very difficult.

The effect of the sampling plan is that there was a good coverage of urban crashes, and nearly complete coverage of crashes involving one or more fatalities. However, the study sample is not necessarily representative of the whole population of crashes involving injury to children as occupants, and it is certainly not representative of all crashes in which children were riding in cars and for whom any injuries may well have been completely prevented by child restraints and adult belts.

Sampling and data collection were conducted throughout the calendar year 1993, plus one month at each end of that year. In total, 288 crash notifications were received. A high proportion, 155 in all (55%) of these notifications were of crashes that did not result in children being added to the study sample. The most important single reason that the crash was dropped from the study (40% of those notified) was that the responsible adults could not be contacted, or did not respond - short of outright refusal to consent - to investigations proceeding before the vehicles were repaired. This was largely a consequence of the study methodology.

In-depth crash investigations are generally conducted in two ways. First, the crash may be attended at the scene, before people and vehicles are removed. This is important for valid analysis of factors important in *causing* the crash. However, the present study was more concerned with the *consequences* of the crash. On-scene crash investigations are exceedingly costly and complex to establish. The number of children involved as occupants is small enough to have made on-scene investigation for this study a very long-term project, as well as costly. However, a big advantage of on-scene crash investigation is that those involved are by definition present, can be interviewed immediately, and will therefore not be "lost" later..

The second main way that in-depth crash investigations are conducted is to follow up the crashes as soon as possible, the procedure in the present case. Studies of injury patterns usually centre on those who are admitted to hospital where, again, the potential interviewees are in a known, stable location. In the case of the present study, however, it was often necessary to interview adults who were not injured and whose children were not admitted to hospital. In such cases it proved very difficult to make contact with adults in a position to assist and to give the necessary consents before the vehicles were repaired or other evidence on the crash was lost or forgotten. In fact, an unexpectedly large part of the crash-investigation team's time was taken up in trying to establish the whereabouts of, and arrange meetings with, responsible adults. A high proportion of the crashes involved people living in poorer socio-economic areas, and many did not have even a telephone through which initial contact could be established. Often a day or two of a team member's time was taken up in abortive attempts to visit the people concerned. Such "lost" cases, however, were known to be predominantly crashes at the lower end of the severity spectrum.

In a recent New York follow-up study that did not include personal interviews with parents or examination of damaged vehicles, and for which ethical approvals were not necessary (Kelleher-Walsh *et al*, 1993), it still proved impossible to follow up 27% of known crashes because parents, drivers or investigating officers could not be located. That experience was very similar to ours, with the additional difficulty in the present study that any delay meant that the vehicle could not be examined and the case would have to be dropped for that reason.

In 23 cases, consent for investigation was refused. This is 10.5% of the cases for which timely contact was established. This refusal rate is slightly higher than the 7% refusal rate for injured patients in a study of adult casualties in Melbourne, but can be regarded as acceptable.

ETHICS AND PRIVACY CONSIDERATIONS

Human research and experimentation in Australia is conducted under guidelines set down by the National Health and Medical Research Council. These guidelines are for research into patterns of health and disease, new medications, invasive investigations and procedures, and studies of injury and injury mechanisms such as the present one. Because it was necessary to contact parents and guardians for permission to obtain information from hospitals on children's injuries, approval to conduct the research was necessary from institutional ethics committees.

In New South Wales, most institutional ethics committees are responsible for the review of research projects undertaken within each Area Health Service of the NSW Health Department. However, the approval of the principal institutional ethics committee in a given Area Health Service does not necessarily cover all hospitals in the area. In addition, the work of some institutional ethics committees is specific to individual hospitals.

Accordingly, approval was sought for the study in the many Area Health Services to be covered by the study. Each institutional ethics committee has its own procedures for approval, in many cases specific to the area or even to the hospital. For example, a committee might insist that the "information letter" (to be given to the responsible adult) must nominate particular committees, areas, or individuals to whom complaints might be directed. Accordingly, although this did not affect the conduct of the study, detailed modifications to the research protocol were necessary to comply with each of the committees' constraints.

The procedure, in short, is directed towards strict ethical review of potentially or actually invasive procedures involving child patients. Few will argue with such safeguards. However, for a study such as this, requiring merely documented information without any necessary personal contact between child and researcher, and covering a wide area of the state, the administrative process for obtaining ethical consents appeared to be unnecessarily cumbersome. Under the procedures extant in late 1992 and early 1993 it could be assumed by potential research groups that the process of gaining necessary approvals would take between three and six months. If the whole state were to be covered systematically, the process could take a year (Smith *et al*, 1994). It is simply impossible to establish a large study at short notice, and it is exceedingly difficult to coordinate committee approvals with the short-term employment of contracted research staff. Accordingly, a few cases were lost at the outset because although crashes were notified, and the basic particulars known, the parents could not be approached because the necessary ethical approvals for the particular region had not been forthcoming before the study commenced.

The process for ethical approval for statewide studies of an essentially epidemiological nature is now under review by the NSW Health Department, and it is to be hoped that considerable streamlining will to be the result.

In addition to all necessary approvals from institutional ethics committees, advice ("approval" was not necessary) was sought from the NSW Privacy Committee on privacy issues. The research protocols and procedures were found to be acceptable by the committee, but both the Privacy Committee and some (not all) of the ethics committees required a clear statement, directed at those from whom consent was sought, that the research data could be subject to subpoena and used in court proceedings. This could account for the rather higher refusal rate (10%) than the 7% reported in the study by the Monash University Accident Research Centre in Melbourne of injured adults to which reference was made above, and was to an unknown extent a barrier to full disclosure of data critical to crash analysis. In at least one case, despite personal willingness for a parent to respond to a request for interview and crash reconstruction, the potential participant's solicitor advised against it. Some states, including Queensland and South Australia (in both cases, states where comprehensive crash studies have been or are being undertaken) specifically protect research data of this kind from subpoena.

The protocol for the study required, *inter alia*, that all personal links to the data were separated from the scientific data and destroyed as soon as practicable after completion of the case file. Thus, the utility of the data for court proceedings is in fact very poor.

Once initial contact with responsible adults was made, they were sent or personally taken a letter describing the aims and procedures of the study, and requesting their assistance (see Appendix 1 for a typical example). Attached to this letter was a consent form (Appendix 2) intended to be signed at the time of interview. This made it perfectly clear that the parents were free to withdraw from the project at any time, without affecting their children's treatment. In practice, of course, the principal contact between the team and the parents was the personal interview.

RELATIONSHIP TO OTHER ORGANISATIONS

A close and ongoing association was maintained with the Road Safety Bureau of the Roads and Traffic Authority, adjacent to which the research team had its premises. In particular, technical data were shared on a day-to-day basis with personnel of the RTA's Crashlab, which routinely collects information on restraints and which conducts laboratory tests for research and development as well as for certification by Standards Australia. This professional interaction was extremely helpful in analysis of some of the technical details concerning vehicles and restraints.

Members of the NSW Police Service gave, with approval from senior officers of the service, invaluable assistance in locating crashed vehicles and facilitating access to them for examination and measurement. In particular, a close and valuable association was developed with personnel of the Accident Investigation Squads in many parts of the state. Officers in this group are particularly skilled in analysis of pre-crash factors, as their focus is on crashes where culpable driving may be the point at issue.

The NSW Ambulance Service established a special system of notification in the metropolitan area which ensured that all potential cases in this catchment were known to the research team and confirmed that suitable cases were not being missed. Their assistance over this period was of great value.

INVESTIGATION PROCEDURES

In summary, the procedure for investigation of each crash involved the following steps:

- notification;
- obtain consents;
- locate vehicle and restraints;
- examine vehicle and restraints;
- conduct interviews;
- reconstruct crash;
- analyse data and impact forces;
- code and enter data into database.

Notification and consents

The inclusion of a child in the study sample could arise in several ways. A child was usually notified to the study by hospital personnel as a result of attendance at a hospital emergency department. Notification could also have been through the NSW Ambulance Service, predominantly the Sydney Division. Crashes involving a fatality, either to a child or to an adult in the same vehicle as a child, were notified through police channels. Some severe crashes were first identified through reports in the media, but were later notified to the team through customary channels.

Notification to the team by hospital personnel of potentially suitable cases differed in practical detail from Area Health Service to Area Health Service and hospital to hospital. Differences occurred because of differences in approvals from ethics committees, availability of willing staff within hospitals, and the data-gathering sophistication of the hospitals. Fortunately, the hospitals seeing most childhood trauma are quite well equipped and were enthusiastic about assisting in this research, with personnel usually already engaged in data-gathering activities associated with the "Childsafe" system for child injury information.

Hospitals not in the "Childsafe" system either had to establish special procedures to assist the CAPFA team, or members of the team had to visit the hospital emergency departments in order physically to scan attendance registers. For such hospitals, there is generally no way of counting the number of child occupant injuries that pass through the system - an injury is an injury, with the background not recorded in routine data.

In most cases the team was notified of the name of the child or children involved in the crash, together with a contact number for the parents and some basic data on the event. The responsible adult was contacted as quickly as possible, by telephone or letter, to establish willingness to participate in the study. If that was established, written consent was then obtained. Withdrawal of that consent, it was made clear in writing, was possible at any time.

In one administration, however, the hospital first contacted the parents for permission to give the team this contact information. This was in full accordance with the local strict ethical procedures, but it did add to delays. There was evidence of a degree of "filtering", with the hospital contact person deciding which parents should be approached for permission. Ironically, by the time notification was received for most of the severe crashes, names and other details had already been published in the media.

In almost all administrations, when the contact person was away on leave or for study purposes, notifications ceased. When they resumed, it was often too late for useful follow-up and crash reconstruction.

Vehicle and restraint examination

As already noted, the necessity for early contact and consent was that the case vehicle and where appropriate the restraints had to be examined before repairs were commenced. As soon as possible the location of the vehicle was established, and an appointment made to attend it for detailed examination and measurement of the damage.
Crush damage was measured by a rig incorporating measuring rods. In suitable cases these measurements were used for part of the input into the EDCRASH module of the EDVAP package of accident analysis programs (Engineering Dynamics Corporation, 1989).

The interiors of case vehicles were carefully examined and measurements taken. Of particular interest were restraint and seat belt mountings, webbing loading marks, contact points between occupants and the vehicle interior, and the degree of intrusion into occupant space.

A comprehensive set of colour photographs was taken, and where appropriate the restraints were taken back to the research team's headquarters for further examination. In other respects the vehicle examination was generally in accordance with the procedures of the National Accident Sampling System

(NASS) of the US National Highway Traffic Safety Administration (Tumbas, undated). Several modifications in detail to the NASS techniques were found to be required to take account of the focus on child occupants and child restraints.

Interviews

The participants, normally the responsible parents, were interviewed in regard to the circumstances of the crash, restraint use and so on. Interviews were conducted informally, but the interviewers had a set list of questions for which answers were required. It was found that a ready willingness to participate was the normal response.

In the case of fatal crashes or those resulting in serious injury the need for urgency was less, as the vehicles were not repaired quickly. This facilitated a sensitive and tactful approach to potentially grief-stricken and guilt-ridden parents.

Crash reconstruction

In as much detail as possible the crash was then reconstructed, with particular attention to the vehicle in which the child or children were riding. Necessary outputs were the type of crash, the change of velocity suffered by the occupants, and the principal direction of force. Damage was coded according to the Collision Deformation Classification (CDC), a seven-character code describing the vehicle damage.

Crush measurements were used as inputs for calculation of the "delta-V" (ΔV, change of velocity experienced by the case vehicle in the crash, commonly but inaccurately referred to as "impact speed"). This is not the speed the vehicle was travelling before the crash scenario developed; it is notionally the change of speed of the vehicle between the instant of impact and the time that the most violent part of the crash is over, within a fraction of a second. Both ΔV and the deceleration forces ("g") felt by the occupants vary with the size of the vehicles and the dynamics of the crash.

For example, take the following case. An average-sized family car, with two passengers, weighing a total of 1,590 kg, swerves on to the wrong side of the road, and hits an oncoming bus head on. The bus is loaded, and weighs 6,800 kg. Each vehicle has been travelling at 48 km/h, but some braking just before the collision reduces the pre-crash speed of each to just over 40 km/h (25 mph). This is the "impact speed". After the collision, the bus continues forwards and comes to rest seven metres from the impact point. The smaller car is bounced backwards, and ends up 14 metres *back* from the impact point. The change of velocity "felt" by the occupants of the car, because of the bouncing effect, is more than the impact speed, and is 77 km/h. The deceleration suffered by the occupants is 38.7 g. In such an impact, serious or fatal injury is probable. In the bus, however, the occupants feel a change of velocity of 18.8 km/h, and a deceleration of around 9 g. Even in the absence of restraint, injury is unlikely to be serious. Accordingly, the ΔV is important because it is a variable closely related to the risk of injury. Well restrained, a vehicle occupant can withstand a much higher ΔV than an unrestrained, but otherwise similar, occupant. Without accurate estimates of ΔV, it is very difficult to assess the comparative performance of restraints or the susceptibility of occupants to injury. For most previous published studies of child occupant injury, changes in velocity have been less carefully estimated or have been disregarded.

As noted above, calculations were performed using the EDCRASH program from the EDVAP package. EDCRASH is a proprietary program based on the CRASH program originally developed by the Calspan Aeronautical laboratories and further developed by the US National Highway Traffic Safety Administration as CRASH 3. The main reason for employing these programs is to obtain estimates of impact speed, change of velocity and deceleration that are more accurate than subjective determinations from observation. The accuracy of the estimates depends on the data available, and is at its highest when detailed information about the scene (at the time of the crash) and the construction of the vehicle are available. Data for vehicle stiffness (resistance to deformation in a specific part of the structure) are available in published literature for most American and Japanese cars, but could not be obtained for Australian-made cars that are not sold and crash tested overseas. Nevertheless, order-of-magnitude data for the stiffness of locally-built cars can be determined. The output of the program is not so sensitive to such data that velocity changes of a reasonable degree of accuracy cannot be determined, and in all cases estimated speeds were reviewed by more than one member of the investigation team for face validity and data accuracy. Nevertheless, when reference is made in this report to change of velocity (ΔV), it should be accepted that the given figure represents an order of magnitude rather than a precise measure to the decimal point.

Injury data

Injury data were sought from the hospitals attended by the injured, supplemented where necessary by information from the parents. In the case of death, coroners' reports were obtained. Non-fatal injuries were coded according to the Abbreviated Injury Scale (AIS 90) (Association for the Advancement of Automotive Medicine, 1990). This, and the Injury Severity Scale, were used to assess and compare the severity of the injuries suffered by children and adults.

The Abbreviated Injury Scale (AIS) is now accepted throughout the world as a systematic way of classifying and assessing injuries. Each injury is classified by body region, defined as follows:

- head (cranium and brain);
- face;
- neck;
- thorax;
- abdomen and pelvic contents;
- spine;
- upper extremity;
- lower extremity;
- external;
- other.

Each injury description is assigned a numerical code according to the following conventions:

AIS Code	***Description***
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Maximum

Injuries are listed in a book published by the Association for the Advancement of Automotive Medicine, which has assumed the lead role in injury scaling.

Before the AIS was developed and published some 20 years ago, there was no objective way of ranking and comparing the severity of injuries, and there was no standard terminology used to describe injuries. The AIS has continued to evolve with the input of clinicians and injury researchers. However, the basic principles on which it was designed have not changed. It is based on anatomical injury, not on physiological measurements of the response of the body to injury. In consequence, there is only one AIS score for each injury, and this does not change over time; in contrast, physiological scores change as the injured person recovers (or fails to do so). In other words, the AIS does not score the *consequences* of injury.

In the present report, for simplicity of presentation, reference is often made to "maximum AIS" or "MAIS". This is the AIS for the most important injury sustained by the child. It may or may not have been accompanied by other injuries to the same individual. It will be noted that there is no AIS for "fatal". This is because death is a physiological state, not a single anatomical injury. In tables in this report, children who were killed are singled out, so that when an AIS is assigned it may be assumed that the child did not die within the period of the study.

Empirical data have shown that the AIS correlates well with the probability of death at the serious and life-threatening levels (AIS 3 or higher), and it is often regarded simply as a "threat-to-life" scale. But other factors are also considered in assigning severity to the AIS, including the potential for response to treatment. Nevertheless, injuries with a serious outcome other than death will not rate as highly as those more likely to kill. This is the case for many neck and brain injuries and for injuries to the extremities, all of which may pose long term threats to health and wellbeing but rate AIS scores of only 1 ("minor") or 2 ("moderate") out of a possible 6 ("maximum", essentially unsurvivable).

For the purpose of this study the AIS was used as intended, but in examining injury as a whole it is important that objective scales are not the only tools used for gauging the severity of childhood injury. And care should be taken with the terminology. For example, an uncomplicated fracture of the vault of the skull rates AIS 2, "moderate", whereas most parents and many medical practitioners using popular parlance would regard a child whose skull was fractured in a car crash as being "severely" injured. Similarly, an amputation of a limb (which happened in one case in this study) rates AIS 2 (moderate) because life is not substantially threatened, yet most people would regard such an injury as devastating. Most of the children in the present study suffered "minor" injury in terms of the AIS, but parents - not to speak of the children - would have found many of the injuries profoundly distressing.

Because each individual injury receives a score, the AIS does not represent the overall extent of injury. To do this, the Injury Severity Score (ISS) was developed by Baker *et al* (1974) in order to derive a single number that would represent overall severity. The ISS is the sum of the squares of the highest AIS code in each of the three most severely injured ISS body regions (which differ in detail from the AIS-defined body regions). An ISS score was calculated for each case in the study, but the MAIS has been used for the presentation of most of the results.

A similar global scale, complementary to the AIS, has now been developed to assess and document the long-term consequences of traffic-related trauma. This has recently been published as the Injury Impairment Scale (AAAM, 1994), but has not been used for the present project. Early evaluations of this new scale are expected to be published soon.

The use of the AIS for childhood injuries needs care, although there are no useful alternatives. It is well documented that an older patient will be more likely to have an unfavourable outcome than a young, healthy person given the same level of physical trauma. Very young children may also be comparatively worse off. Earlier editions of the AIS did not always reflect the relative severity of injury in very young children, particularly in relation to brain injury and blood loss, and revisions were made to AIS 1990 to take account of these factors.

There have been several evaluations of the AIS and ISS, but few specifically directed towards childhood injury. However, Wesson *et al* (1986) conducted a prospective study to test the validity of the Injury Severity Score in a group of 250 children with major trauma. The ISS was compared to mortality and functional status at discharge, and six months after the injury. The predicted validity of the ISS was found to be good. The mean ISS was 40 in the non-survivors and 22 in the survivors. There was only one death in a child with ISS of under 30. At follow-up there was an unexpectedly high incidence of physical functional limitation, which affected nearly half the children. Apart from that, the ISS appeared to these authors to be a reliable and valid measure of injury severity in children.

An additional method to garner injury information was employed for the present project. In many cases where injuries were minor, unspecified in hospital records and ephemeral, such as bruising that could show contact of the restraint straps with body parts, parents were asked to complete a proforma diagram showing the location of bruise marks and giving other information on the injuries. This proved to be a valuable source of hitherto unrecorded information on injuries that revealed something about impact loadings but that were not recorded in hospital records because of their "insignificance".

The database and data analysis

All the data were entered into a relational database developed for this project using Open Access software.[2] The database establishes links between vehicles, occupants, restraints and injuries. This database, together with a proprietary package of statistics programs, was used for data analysis.

The data structure is as follows:

- Case: general information including speed limits, location,

2 Software Products International, San Diego.

weather, object struck;

- Vehicle: make, model, mass, dimensions, damage codes, crush profile, ΔV, interior assessment;

- Occupant: for each nominated vehicle occupant age, sex, mass, height, medical condition, type of restraint available, whether worn, adjustment rating, condition before and after the crash, intrusion factor, ejection factor, airbag factor;

- Injury: for each injury body region, description, AIS number and code, objects contacted, intrusion.

The database also contains reference information about vehicle makes and models, types of restraints and makes and models of restraint. It contains even more data than could be analysed for the purpose of the present report. It has been further developed for use by the Road Safety Bureau of the RTA to track investigations into vehicle and equipment safety.

6 STUDY RESULTS

OVERVIEW

Numbers

For the calendar year 1993, plus a month at each end of it, there were 288 notifications of potentially valid cases. There were often several "cases" in one crash. After excluding crashes for which suitable contacts could not be established, refusals, and invalid crashes (bus crashes, children over the age limit and so on), data for 247 children aged 14 or younger in 131 crashed cars were gathered for the study and became the sample. In addition, some data for 212 older children and adults in the same crashes were also gathered for the purpose of comparison and further estimation of the severity of crashes.

Areas

Table 1 - Crashes by speed limit in location of crash

	CAPFA study		NSW 1992 (all accidents)*	
Speed limit	Number	%	Number	%
< 60 km/h	71	54.2	36,248	71.0
70 km/h	6	4.6	2,059	4.1
80 km/h	20	15.3	2,941	5.8
90 km/h	6	4.6		
100 km/h	23	17.6	6,514	12.9
110 km/h	5	3.8	1,024	2.0
Other			1,719	3.4
Totals	131	100.0	50,505	100.0

* *Including pedestrian accidents*

The crashes were predominantly in urban areas, as defined by the prevailing speed limit. The distribution of crashes by speed limit is shown in Table 1, which also shows the distribution for all 1992 accidents in New South Wales (Road Safety Bureau, 1993).

Published RSB figures do not allow direct comparisons, but this table indicates that the sample included a statistically significantly higher proportion ($p<0.001$) of outer-urban and country-area crashes than is typical for the state as a whole. However, the coverage is probably not significantly unrepresentative of injury-producing vehicle crashes, especially those involving severe injury.

The vehicles

The case vehicles in the study were all passenger cars or passenger car derivatives, including "people-carrier" passenger vans with more than two rows of passenger seats. The case vehicles in the study, by the number of models and number of cases, are listed in Table 2.

Given the distribution of models throughout the vehicle population there was a fairly representative distribution of models throughout the sample, with the only standout feature being the high proportion of injured children who had been riding in a Toyota Tarago or Toyota Landcruiser. This is a reflection of the fact that these "people carriers" are often used - indeed, purchased - to carry large numbers of people, including children, at a time. There were cases in which one of these vehicles had crashed while almost every passenger seat in all three rows had been occupied by a child. The use of these vehicles for child transport is discussed in more detail later in this report.

The year of manufacture of the vehicles ranged between 1966 and 1993, with a mean of 1984 (standard deviation 5.6 years), making the mean age about 9 years. This mean age is very close to the mean age for the passenger vehicle fleet in Australia, which was 10.2 years in June 1993 (ABS, 1993). Also similar to national vehicle census data is the proportion of the case vehicles being over five years old, at just over three-quarters.

Crash types

The principal directions of force at impact are shown in Table 3. This is to some extent an over-simplification, because many collisions were side-swipes and other complex impact configurations to which it was difficult to assign one single force direction. Aggregating the figures in this table shows that predominantly frontal impacts accounted for 50% of the crashes and 55% of the casualties, side impacts 27% of the crashes and casualties, rear impacts 15% of the crashes and 11% of the casualties, and rollovers 7% of the crashes and casualties. This distribution is consistent with data gathered by other crash investigators in Australia, such as those reported by Fildes *et al* (1991).

Table 2 - List of case vehicles

Case vehicles (make and model)	Number of vehicles	Percent of vehicles	Number of cases	Percent of cases
Ford Falcon/Fairmont/Fairlane	19	14.5	32	12.9
Holden Commodore/Statesman	14	10.7	24	9.7
Toyota Corolla	6	4.6	7	2.8
Toyota Tarago	6	4.6	21	8.5
Toyota Corona	5	3.8	8	3.2
Toyota Landcruiser	4	3.1	10	4.0
Daihatsu Charade	4	3.1	9	3.6
Holden Camira	4	3.1	7	2.8
Mitsubishi Sigma	4	3.1	7	2.8
Mazda 323	4	3.1	6	2.4
Toyota Cressida	3	2.3	6	2.4
Holden Gemini	3	2.3		
Holden Torana	3	2.3	5	2.0
Mitsubishi Magna	3	2.3	5	2.0
Nissan Bluebird	3	2.3	5	2.0
Ford Laser	3	2.3	2	0.8
Others	43	32.8	94	38.0
Totals	131	100.0	247	100.0

Table 3 - Principal directions of impact force (PDOF)

	Crashes		Cases	
Force direction	No.	%	No.	%
Centre front (355-005 deg)	41	31.3	86	34.8
Right front (006-045 deg)	17	13.0	31	12.6
Left front (293-354 deg)	8	6.1	18	7.3
Right side (046-112 deg)	17	13.0	35	14.2

Left side (203-292 deg)	19	14.5	33	13.4
Rear (113-202 deg)	20	15.3	27	10.9
Rollover without first impact	9	6.9	17	6.9
Total	131	100.0	247	100.0

Side impacts were the crash configuration most likely to result in significant injury, with 23 of the 68 case children in side impacts (34%) sustaining injuries of AIS 2 or greater, and 31 of 135 cases in frontal and near-frontal crashes (23%) resulting in AIS 2+ injuries.

Change of velocity

For not all crashes (for example, rollovers and many sideswipes) is the calculation of ΔV valid for the derivation of the severity of the crash, but as described earlier it was calculated when appropriate. For frontal and near-frontal *crashes* where calculation of ΔV was appropriate, the range of ΔV values was between 14 km/h and 90 km/h, with a mean of 46 km/h and mode 20 to 30 km/h. For side impacts, the range was eight to 62 km/h, mean 28 km/h, and rear impacts 17 to 44 km/h, mean 28 km/h.

The mean ΔV value for the *cases* (children) was 39.0 km/h, but the distribution was essentially bimodal, with a peak at 20 to 30 km/h and a secondary peak at 60 to 70 km/h. These peaks are related to the speed limit zones in which the sample crashes most commonly occurred. There were 35 case children in crashes with a ΔV of 60 km/h or more. Again, the figures for crash changes of velocity are consistent with those recently reported by Fildes *et al* (1991) in the Monash University study of adult casualties in Victoria, with a mean in the present case that is rather lower because of the more liberal requirement for entry into the study (attendance at a hospital rather than admission, which was the criterion in the Monash study).

The child occupants

The ages of case occupants (ranging from a few days to 14 years) were distributed quite evenly throughout the range, with a slight bias towards the under-fives (see Table 4) which is likely to be to some extent a result of the sample selection procedures. The average age was 6.7 years (standard deviation 4.3). The male/female distribution of the children was very even, with 125 males in the sample and 122 females.

Table 4 - Case children, age distribution

Age	Males	Females	All
0-4	48	47	95
5-9	37	39	76
10-14	40	36	76
Total	125	122	247

The age distribution of all adult occupants (15 years and over) in the sample gave a mean of 33.8 years, although 83% of all adult occupants (including many children in their older teens) were aged under 40 years. Similarly, the mean age of drivers was 33.9 years, with 70.6% being aged under 40 years and 36.5% under 30 years of age. These figures for driver age were not significantly different from the ages of drivers involved in all accidents in NSW.

The injuries overall

The numbers of principal injuries (maximum AIS) are tabulated in Table 5. The main single injuries in this sample of crashes were predominantly minor (AIS 1) or moderate (AIS 2), with four out of five of the injured children falling into this category. The uninjured children had been taken to emergency departments where doubt existed on their status, or simply for "checking".

Table 5 - Distribution of maximum AIS values and ISS scores

Maximum AIS	Number	%		ISS	Number	%
0 - no injury	44	17.8		0	44	17.8
1 - minor	141	57.1		1 - 2	139	56.3
2 - moderate	26	10.5		3 - 4	8	3.2
3 - serious	15	6.1		5 - 9	24	9.7
4 - severe	2	0.8		10 - 16	7	2.8
5 - critical	2	0.8		17 - 27	8	3.3
7 - fatal	17	6.9		Fatal	17	6.9
Total	247	100.0		Total	247	100.0

Naturally, the proportion of children in the sample who were fatally injured is greater than would be the case for a representative sample of injured children, because the sampling was deliberately intended to include all fatally injured children in the state over the study period, if possible. The distribution of the Injury Severity Score (ISS) for children who were non-fatally injured is similarly skewed, with some 56% of the sample, and 68% of injured children having a score of 1 or 2.

Restraints used by occupants

Among adults, 93% claimed or were reported as having been wearing the lap/sash belts available for their seating positions. However, no special effort was made to verify these figures. All five of the adults for whom lap-only belts were available claimed or were reported as having been wearing them in the accidents.

The restraints being used by children in the sample are tabulated in Table 6. This table also represents a general overview of the distribution of maximum AIS by type of restraint. (More details, including the ages of the children involved, will be found in the sections of the report relevant to particular restraints.) The remainder of the children in the sample (19, 7.7%) were not wearing an available restraint, or were in a position where no restraint was available.

Table 6 - Restraints used by restrained case children, by maximum AIS

	Maximum AIS									
Restraint type	0	1	2	3	4	5	6	Fatal	All	%
Lap/sash seat belt	11	83	13	7	1	0	0	6	121	53.0
Lap-only seat belt	5	21	3	2	1	0	0	3	35	15.4
Infant capsule	3	0	1	1	0	0	0	1	6	2.6
Forward-facing seat	16	16	3	0	0	1	0	1	38	16.7
Rear-facing seat	1	2	0	0	0	1	0	0	4	1.7
Booster cushion/seat	8	12	3	0	0	0	0	1	24	10.5
Total	44	135	23	10	2	2	0	12	228	100.0

About half the sample were restrained in lap/sash seat belts, as normally installed in passenger cars, and another 15% were using lap-only belts in centre seating positions (almost all in the rear, as centre front seating positions are now very rare in Australian cars), or in third-row seats of multi-passenger vehicles. The remainder, about one-third of the sample, were using child restraints of one kind or another. Of these, about half were using a forward-facing child seat with built-in harness, and most of the remainder were using a booster seat or cushion, with either a lap/sash belt or a lap belt for restraint. In one case, however, a booster was used in the centre seat in association with a child's shoulder harness, and this case has been included among other booster cases for the purpose of analysis. Six children in the sample were restrained in a rear-facing infant capsule and another four in a rear-facing child seat.

CHILDREN IN CHILD RESTRAINTS

Infant capsules

Six children in the sample were restrained in infant capsules. Four of these capsules were in the centre rear position, and two in the left rear position (behind the front-seat passenger). In addition, there was one child for whom a capsule was available who was probably being held in the arms of an adult front-seat passenger, and this case is discussed further below. Infant capsules are designated by Standards Australia as "Type A1 - rearward-facing enclosing restraint, suitable for children whose mass is up to 9 kg, **FIGURE 1 - Side impact causing death of correctly restrained infant in capsule in centre rear position (28812)**

and corresponding supine length is up to 700 mm" . In all cases the children, aged from a few days to four months, were within the mass range designated for these restraints.

In all cases in the study the system used to restrain the child in the capsule was a "body band", a pair of overlapping straps about 150 mm (six inches) wide, secured by "Velcro" fastening material, and with no webbing harness.

One of the children in these capsules (28812) was killed. The baby girl was aged two months, and was properly restrained in the rear centre seating position of a 1984 Holden Commodore (Figure 1) that was struck on the right (driver's) side by another sedan at some 30 to 40 km/h, with resulting intrusion amounting to some one-third of the width of the vehicle, with the maximum extent near the B pillar (between the front and rear seats). The driver was trapped, and her pelvis was fractured. The cause of the child's death was extensive subarachnoid haemorrhage over both posterior parietal and entire occipital lobes of the brain, without fracture of the skull or spinal column or injury to the spinal cord. Haematomas were apparent on the left face and forehead, and the left

FIGURE 2 - Collision followed by rollover; head injuries to child ejected from capsule, probably incorrectly installed (122)

posterior surface of the scalp. Accordingly, it is likely that the interior surface of the capsule was driven on to the child's head by a combination of the child ramping up the interior of the capsule within the body band, and the intrusion caused by the impacting car. *This was the only child in the entire study who was killed while correctly restrained in a correctly installed child restraint*.

Two children restrained in capsules were seriously injured. In one of these, a male infant (122) aged six days was in an incorrectly-installed capsule in the rear centre position of a 1983 Ford Meteor. The car collided with another sedan on a country road, and then rolled (Figure 2). The main impact was from the right front (ΔV 34 km/h), and the 60-year-old driver was killed, receiving unsurvivable head injuries. The front-seat passenger, the 34-year-old mother of the children in the car, received minor injuries, predominantly to the head, with extensive body bruising from seat-belt loadings. After the crash, the infant was found dislodged from the restraint and lying at the feet of his mother, having suffered head and face injuries, probably from contact with the interior of the car's roof. The bassinet part of the capsule was on the mother's head. It was found that the top tether strap had been correctly attached to the car, but that the lap belt in the centre rear position had not been used to secure the body of the capsule. This would have caused the restraint, complete with child, to fly around the interior of the vehicle during the complex dynamics of this crash. Further, although it was found that the body band that held the infant in the restraint had been fastened, in the configuration it was found after the crash it would have been loose for the size of the child. In the same car, another child in a forward-facing child seat in the rear received minor external injuries, and later examination showed that the restraint harness in the seat had been adjusted very loosely for a child of its weight and height. This finding tended to strengthen suspicions that the infant's restraint capsule had also not been installed in compliance with good practice and the manufacturer's instructions.

FIGURE 3 - Collision with bus: three uninjured children in rear, centre one in capsule (4614), other two in a child seat and in a seat belt/booster

The other occupant of an infant restraint to be seriously injured was a five-week old female (5713) in the rear left position of a 1977 Toyota Corona that was involved in a high-speed frontal impact with a bus. Both the front-seat passengers of the car were killed. The child suffered a skull fracture, but without significant after-effects.

Three infants in capsules were not injured. A two-week-old infant (4614) was correctly restrained in a correctly installed capsule in the centre rear position of a 1984 Holden Camira that hit a bus with a right-front impact, with a ΔV of about 55 km/h (Figure 3). The child was unhurt. The two adults in the front seats received bruises from belt loadings, as did the two children in the outboard rear seats, one in a correctly-used forward-facing child seat and the other using a booster.

Two other infants escaped unhurt (5011 and 17414) in comparatively low-speed urban collisions, being restrained in correctly installed and used capsules in the rear-left seating position and rear-centre positions. Other occupants were also uninjured.

A four-month old child (26613) for whom a capsule was installed on the rear seat of a four-wheel-drive wagon was ejected during a high-speed rollover that ended with a collision. The child was seen to come out through the front passenger's window. Immediately after the crash, the body band was found to be open. It is possible that the child was being nursed by the front-seat passenger, but as both adults were killed and the vehicle extensively damaged, no firmer conclusions could be reached.[3]

Forward-facing child seats

These are designated by Standards Australia as "Type B - forward-facing chair with six-point harness including crutch straps, suitable for children whose mass is within the range 8 kg to 18 kg". This is equivalent roughly to six months to five years of age, but there is a considerable range in age-to-weight relationships that can be confusing for consumers. For example, a boy of mass 8 kg may be aged anywhere between four and eleven months. These restraints are required (in terms of the Standard and by regulation) to be used with top tethers, using a mounting point in the vehicle mandated by an Australian Design Rule. The effect is that all such seats should be mounted in other than front seating positions.

There were 38 children in the sample restrained in these forward-facing child seats with their own harnesses. There were no cases of children being unrestrained when there was an unused child seat in the car. The ages of children thus restrained are shown in Table 7.

Table 7 - Ages of children in forward-facing child seats

Age range	Number	%
< 1 year	9	23.7

3 [2] Several cases in which small children were being held in adults' arms are documented later.

> 1 < 2 years	17	44.7
> 2 < 3 years	8	21.0
3 + years	4	10.5
Total	38	100.0

The range of ages of children in these restraints was four weeks to 3.5 years, with a mean age of 1.5 years. There were 22 male children and 16 females. All children were comfortably within the upper range of the designated mass and height for this type of restraint. However, there were four children under the recommended mass range. Three of them were uninjured in low-speed collisions, but the fourth (13413) received critical head injuries in a rear-end collision when seated in an incorrectly-installed restraint (case described in more detail below).

In all cases the restraints were installed in the rear seating positions. Installation in the front would have been incorrect, because all seats require a top tether, and mountings for top tethers are behind the rear seats. In nine cases, the installation was in the centre rear position. Of the 28 cases where the restraints were installed in rear outboard positions, 20 were installed in the left rear seat, behind the front-seat passenger. This is presumably because the restrained child is in that position more easily seen by the driver. All but two of the seats (one brought in from Europe, and one a superseded model) complied with current Australian Standards requirements.

For this group of restrained children, there was no correlation between overall injury severity (ISS) and ΔV when the latter was calculated. As will be seen, this is in contrast to the positive relationship for children using adult belts.

No injuries were detected on medical examination for 16 children in this sub-sample. In another 17 cases, injuries were all minor, with maximum AIS scores of 1.

This left only five cases where any individual injury was AIS 2 or more, and overall injury severity ISS 5 or more. Of these five, three (two aged two years, and one aged three) were in frontal impacts, one (aged seven months) in a side impact, and one (five months old) in a rear impact.

FIGURE 4 - High-speed frontal crash resulting in the death of a child from neck injuries resulting from incorrect routing of adult shoulder belt over front of child restraint(22413)

The worst of these was a fatality, the only one among children using a forward-facing child seat. This was a male child (22413), aged just over two years, mass 12 kg, height 860 mm. The restraint was mounted in the left rear seating position of a 1980 Mitsubishi Sigma sedan. The crash occurred in a semi-rural area on a main road. The Sigma veered to the wrong side of the road, glanced off one oncoming passenger car, then collided head-on with another passenger car (Figure 4). The ΔV was 65 to 70 km/h. The female driver survived with fractures of the facial bones and extremities, and a four-year-old girl wearing a three-point lap/sash belt in the front passenger seat received generalised soft tissue injuries. The two-year-old boy in the child seat died soon after arrival at hospital, from injuries to the neck (including a fracture-dislocation at C1-C2). At first glance, therefore, this is the kind of neck injury feared by those who are uncomfortable with the practice of restraining young children facing forwards.

FIGURE 5 - Bruising over fatal fracture-dislocation of the neck from shoulder belt incorrectly routed in front of child restraint (22413)

However, further examination revealed several other factors that contributed to the child's injuries. The pattern of contact bruising on the child's front showed a line of bruises across his neck, from under his left ear down to the right clavicle (Figure 5), with another line of bruises and abrasions over his lower left abdomen. The pattern was consistent with the configuration of an adult three-point belt. The child restraint had had the soft cover removed, leaving only the plastic shell. The webbing of the child restraint was in place, but was not threaded through the shell correctly. There were no loading marks on the child harness, but there were clear loadings and a skin trace on the car's static (non-retractable) lap/sash belt. It is likely that the restraint had been placed in the seating position, but not properly secured to the vehicle. No top tether had been used to hold the top of the restraint. The child harness in the seat had not been used. The lap/sash belt had been routed in front of the seat and the child, in an attempt to hold both together. The configuration of the seat, with prominent wings at the sides of the head, would have prevented the shoulder part of the belt from lying close to the child. During the crash, the child would have been propelled forward at the speed of impact into the seat belt. As mounted, the configuration of the webbing would have brought the sash portion directly across the neck of the child, and this is likely to have been what caused the fatal injury. There was gross oedema of the brain, but no external evidence of head contact. This, therefore, was a very poorly installed and used child restraint.

FIGURE 6 - Rear impact resulting in collapse of the front seat-backs and head injury to child in restraint in rear (13413)

Another injury that resulted at least in part to poor installation was suffered by a five-month girl (13413) in a Type B seat in the left rear position of a small sedan (a 1993 Suzuki Swift; see Figure 6). The car was stationary in traffic when hit from the rear by a Holden Commodore, resulting in a ΔV of not more than 30 km/h (20 mph). It was pushed forward into the car in front, impacting at slow speed. The backs of both the driver and passenger seats in the Suzuki collapsed. The weight of the female passenger in the seat in front of the child restraint was 70 kg. The child's head impacted either the

FIGURE 7 - Seat-back collapse, showing resulting proximity to child

restraint

top of that passengers's head (the adult suffered a bruised scalp in the appropriate position) or the top of the head restraint on the front passenger seat (which showed evidence of contact). See Figure 7 above, which shows the resultant proximity of seat back and child restraint. The child suffered a comminuted fracture of the roof of the orbit among other head injuries, together with brain damage the permanence of which is not yet known. In addition to the front seat collapse, the head impact was facilitated by incorrect installation of the child seat. The retractable lap/sash belt had been routed around the base of the seat, and the top tether strap had not been employed. The seat was thus grossly unstable fore and aft. In addition to the above mechanisms, the back of the rear seat became detached from its mountings, thus further loading the seat/child combination.

A female child aged seven months (423) was restrained in the rear right seating position of a 1989 Holden Camira that was hit on the right side (ΔV about 45 km/h) by an out-of-control articulated truck/trailer on a rural highway, resulting in head injuries for the child, and a fractured femur. The driver, in front of the child, was killed. The top tether had not been employed, and as the restraint responded to intrusion caused by the impacting truck, the buckle of the adult seat belt used to install the restraint was distorted and smashed by the frame of the child seat. The particular style of seat in this case provided little or no side protection to the head of a child.

Table 8 - Contact points for two principal injuries: children in Type B forward-facing child restraints

		Point of contact						
	Body region	Child restraint	Door/ window	Car seat	Console	Roof	Glass	No contact
First injury	Head		1	1		2	2	
	Face				1		2	
	Neck	1						1
	Thorax	1						
	Abdomen	1						
	Extremities			3	1			
	External							
Second injury	Head							
	Face			1			1	
	Neck	1						

	Thorax							
	Abdomen	1						
	Extremities	1	2					
	External	3						
Totals		9	3	5	2	2	5	1

No other injuries among children restrained in forward-facing child seats were scored more than AIS 2, and were predominantly bruises, lacerations and abrasions. Most injuries were bruising and abrasion from belt loadings, from extremity contact with the seat in front of the child, and lacerations from flying glass (see Table 8). There was one minor soft tissue injury of the neck, without contact. It was suffered by a male three-year-old (13312) in the centre rear seat of a station sedan which, while stationary in traffic, was hit in the rear by a bus. The German child seat (which had been personally imported) had no top tether, although an idiosyncratic attempt had been made to restrain the upper part of the seat with the shoulder portions of the outboard adult belts.

A facial injury was suffered by a six-month-old boy (6912) in the centre rear position of a station sedan involved in a minor frontal impact (ΔV 20 to 25 km/h) when he swung forward in the seat, which was restrained only by the lap belt and with no top tether, and hit his head on the console between the front seats.

Thus, there were very few injuries among children restrained in forward-facing Type B seats, and none more than trivial in those that were correctly installed and used. There were, on the other hand, several cases in the study of children in Type B restraints who were not significantly injured in very heavy crashes. They were as follows.

FIGURE 8 - Collision with tree in country; child in restraint in centre rear position uninjured (13513)

A boy of just under two years of age (13513), was restrained in the centre rear seat of a 1990 Holden Commodore which ran off a country road and hit a tree with a left frontal impact that totally demolished the left front and side of the car (Figure 8). Because of the sideswipe component and high degree of distortion of low-stiffness structures, the ΔV could only be an estimate, but it was one of the highest in the sample and would have been in the region of 80 to 90 km/h. The front passenger was killed. The child restraint mounting straps, including the top tether (which was correctly routed to its mounting point on the floor behind the rear passenger seat) showed evidence of loading. There was no intrusion into the child's space, and he sustained no skeletal or significant soft tissue injury, simply some facial lacerations from flying glass.

FIGURE 9 - Head-on collision with another car; eighteen-month-old girl in child restraint in left rear position uninjured (18613)

A head-on collision occurred on a country highway between a 1991 Ford Falcon station sedan and another sedan, with the ΔV for the Ford being in the order of 70 to 75 km/h Figure 9). Both restrained drivers were killed, and other adult passengers seriously injured. An eighteen-month-old girl (18613) was restrained in a correctly-installed restraint in the left rear position. The seat belt used to install the child seat showed heavy loading marks. The bolt securing the top tether mount had sheared within its threaded fitting on the floor of the wagon's goods area, but this was probably because it was hit by luggage. Again, the child suffered no skeletal or significant soft tissue injuries.

FIGURE 10 - 1992 Ford Falcon, change of velocity in frontal collision over 60 km/h; nine-month-old in forward-facing Type B seat sustained only bruising (27013)

Another very high-speed crash was a head-on collision between a 1992 Ford Falcon and a Jaguar XJS coupe on a sweeping bend on a country highway. Both vehicles were reported to have been travelling at about 90 km/h, and there were no signs of either vehicle having braked before impact. The Ford ΔV was in the range of 60 to 70 km/h (Figure 10). Both cars were severely damaged. The passenger in the Ford was killed, and both drivers sustained multiple injuries. In the rear of the Ford was a nine-month-old infant (27013) in a forward-facing seat complete with top tether. The child was uninjured in the crash apart from some bruising from harness loads and lower-limb contact with the centre console, perhaps because the lower part of the seat became detached from the adult belt in the crash.

FIGURE 11 - Toyota Tarago in which three adults killed; three-year old centre seat, second row, sustained broken arm and lacerations from flying glass (28214)

A Toyota Tarago multi-passenger vehicle came into heavy frontal impact with an out-of-control sedan, with a ΔV of at least 60 km/h (Figure 11). The driver, front-seat passenger, and another adult passenger in the second seating row were all killed. In the centre position of the second row was a three-year-old male child (28214), restrained in a forward-facing Type B seat with a lap belt and top tether. The boy suffered a broken arm, perhaps in contact with the passenger beside him, and facial lacerations from flying glass. He had no significant soft tissue injuries.

A male child aged two years (9313) was restrained in the rear left seating position of a 1973 Toyota Crown sedan, which was involved in a frontal collision, ΔV about 55 km/h (Figure 12). The restrained driver was hospitalised in a serious condition as a result of injuries received through intrusion of the occupant space. A seven-year-old

FIGURE 12 - Two-year-old restrained in child seat in rear left position; heavy webbing loadings with bruising and fractured clavicle, but no neck injury (9313)

boy, using a lap/sash belt in the front passenger's seat, hit the windscreen and surrounds and suffered a depressed fracture of the skull. The child in the forward-facing restraint suffered heavy webbing loadings, with extensive bruising and a fractured clavicle. The restraint structure was cracked in the collision. However, no other injuries to this child were recorded, and his neck was unharmed.

There were another four children restrained in forward-facing child seats who received no significant injuries in frontal impacts of around 50 km/h ΔV or higher.

Two of these were in the rear (second row) bench seat of a light commercial van, a 1991 Mitsubishi Express. The van was side-swiped on a country road by an oncoming light (one-tonne) flatbed utility, the tray of which tore into the side of the Mitsubishi, resulting in intrusion that killed the driver and a ΔV of around 45 to 50 km/h. The Mitsubishi van had been equipped with a bar across the vehicle behind the seat, to which top tether straps were properly attached. In two seats thus linked to the bar were two boys, a three-year-old (5811) and another aged eighteen months (5812). The older boy required some sutures for a laceration to his head, but they were otherwise unharmed.

Two other children (4615, 12212) survived without significant injury frontal crashes at over 50 km/h ΔV that were not fatal to adults.

Further, two restrained children survived lower-speed side impacts in which adults were killed. In one, a one-year-old male (24413) was in a forward-facing convertible seat in the centre rear position of a 1979 Range Rover that hit a tree on the left side, causing the death of the left front passenger. In the other, a one-year-old (123) was rather loosely restrained in a child seat in the right rear position of a 1983 Ford Meteor which collided with another sedan on a country road, and then rolled. A baby in a capsule restraint was dislodged, as already discussed above (see Figure 2).

Two other children survived without injury rollover crashes in which adults died. One was an eighteen-month-old girl (914) in the rear left position of a Toyota Landcruiser that hit a rock face and then rolled, and the other was also a girl aged eighteen months (23213) who was in a child seat in a multi-passenger van carrying many children that rolled; this crash is discussed further in the context of adult belt use.

Rearward-facing child seats

There were only four children in the sample restrained in rearward-facing seats, all being of the "convertible" type which can be turned to face forward when the child is old enough. These are "Type D" seats, suitable for children within the mass range of 8 to 18 kg. All the children in this sub-sample were aged under six months, and all were under this mass range.

The only significantly injured child of this four was a male aged four months, mass 6 kg (23412). The restraint was mounted in the left rear seat of a Toyota Corolla by the car's lap/sash seat belt, complete with a top tether. After running off an urban freeway the car rolled several times, although with little permanent intrusion resulting. In the crash the child received fractures of the skull with resulting unconsciousness and neurological deficit (AIS 5), minor lacerations of the scalp and facial bruising. The child's head probably hit the roof rail, but he had been under additional threat from the presence on the rear seat of several rolls of wallpaper, each of up to 2 kg in weight.

The other collisions involving these restraints were all minor, although one frontal crash (ΔV of 27 km/h) occurred during the child's very first ride in a motor vehicle, in the rear left seat of a Subaru station wagon while still in sight of the hospital where he had just been born (10514).

Booster cushions and seats

These are designated by Standards Australia as "Type E - a restraint consisting of a cushion, chaise or converter used in conjunction with an adult lap-sash seat belt . . . ". They are suitable for children whose mass is between 14 and 32 kg (very approximately two to 11 years of age). The seats may be hard or soft. Many have an integral backrest.
There were 24 children restrained with the aid of booster seats. The ages of the children were as shown in Table 9.

Table 9 - Ages of children restrained in booster seats

Age range	Number	%
> 2 < 3 years	3	12.5
> 3 < 4 years	10	41.7
> 4 < 5 years	6	25.0
>5 < 7 years	5	20.8
Total	24	100.0

The range of ages of children in these restraints was two years to six. There were 12 male children and 12 females. All children were within the lower range of the designated mass and height for the use of booster seat restraint, and all were comfortably within the upper range.

Eight of the children received no injuries, and 12 had AIS 1 injuries. Three received injuries of maximum AIS 2 (one three-year-old in the front passenger seat, and two in the rear left seat, aged three and four years), and one in the rear centre position was killed.

The use of a booster in the centre rear position is usually unacceptable, because of the lack of a shoulder belt in that position in most cars. In the case of the fatality (18412), a three-year-old girl of mass 18 kg and height 970 mm was incorrectly restrained in a 1984 Ford Telstar by a lap belt on a soft booster "chaise" that has its own seat back. The crash was a full frontal impact into a tree, with a calculated ΔV of over 70 km/h (Figure 13). The driver died from closed head injuries and a fracture dislocation of the

FIGURE 13 - Frontal impact with tree; child using lap belt with booster in centre rear position died from head and neck injuries (18412); the rods are being used for damage measurement

upper cervical spine. The soft and highly compressible nature of the booster seat (see Figure 14) allowed the child to swing far forward and downwards, with head contact towards the front end of the console between the front seats. The tension/distraction of the child's neck, together with the head contact, resulted in fracture-dislocation at two places in the child's cervical spine. There were also substantial bruising and abrasions in the lower abdomen as a result of the lap-belt loading. Because the head contact appeared to be such a long distance from the child's seating position, this crash was replicated on the Crashlab sled. At a simulated impact speed of 50 km/h, the combination of a lap-only belt and a compressible booster allowed so much excursion that the dummy's head hit the sled floor.

Another of the injured children, a boy aged three years (18911), was effectively only restrained in a lap belt while sitting in a booster seat. This was the same (compressible) type of seat as the above-mentioned, mounted in the rear left seating position of a 1984 Ford Econovan multi-passenger van. The seating position was equipped with a lap/sash

FIGURE 14 - Dangerous combination of lap belt and booster seat, allowing excursion of torso and head contact with fatal neck injury (18412)

seat belt, but the sash portion of the belt had been led behind the child booster seat. The crash was a right-front impact at a ΔV of only 22 km/h, followed by a half roll. The configuration of booster seat and seat belt use allowed torso excursion to the extent that the child's head contacted the back of the seat in front of him, and his left fibula was fractured from an associated contact just below the knee.

Also in a rollover, the hand of a four-year-old girl (28911) in a booster in the left rear seat of a 1983 Mazda 323 came out of the side window, and fingers were amputated. She also suffered AIS 2 head injuries, as the roof of the car collapsed. The booster, once again, was the soft type used in the two cases described immediately above, but in view of the crash dynamics and intrusion the construction of the booster did not materially affect the injury outcome.

Another three-year-old male (2412) was using a booster with a lap-sash seat belt in the front passenger seat of a 1982 Mitsubishi Magna that was in a right-frontal collision with another sedan at a ΔV of 24 km/h. Even at this comparatively low speed, excursion was enough to result in a hairline fracture of the left patella and other evidence of contact with the dash panel.

FIGURE 15 - Heavy frontal collision, 1982 Daihatsu Charade; three-year-old in booster with three-point belt in left rear position sustained minor bruises only (27813)

All the other injuries in booster seats were minor, and were predominantly bruising from seat-belt loading. Some of these children escaped significant injury despite being involved in very violent crashes. For example, a three-year-old girl (27813) was in the left rear position of a 1982 Daihatsu Charade on a soft chaise booster. The car came into frontal impact with an out-of-control oncoming (larger) Toyota on a straight country highway, at a calculated ΔV for the Charade of over 70 km/h (Figure 15). Damage was very extensive, with frontal crush extending back to the A pillar. Both adult front occupants were killed, but the child suffered only superficial head injury and no other soft tissue injuries. In another case, a four-year-old (9314) using a firm booster supplemented by a child's shoulder harness in the centre rear position of a 1973 Toyota Crown rode out a frontal crash of calculated ΔV of around 55 km/h with only bruising and abrasion of the shoulders and hip from belt loading, and no other injuries.

ADULT BELTS USED BY CHILDREN

Lap/sash seat belts

As noted in the literature reviewed earlier, a point of interest for many years has been the extent to which children may be placed at risk by using adult belts, because of the incompatibility of the size and shape of the typical child with the geometry of the typical seat-belt installation. The importance of this question has diminished over recent years with the ever-increasing availability and use of dedicated child restraints (including booster seats) that are much more appropriate for different ages and sizes of children. Nevertheless, many children still use adult belts alone, and in many cases the size of the children so restrained is in principle unsuitable for this kind of restraint.

Indeed, in the sample of children aged 14 years or under entering into this study, easily the commonest single type of restraint used was the lap/sash seat belt. This is not

Table 10 - Maximum AIS, by whether lap/sash belt used

	Lap/sash worn		Lap/sash not worn	
MAIS	Number	%	Number	%
0-None	11	9.1	0	0.0
1 - Minor	83	69.0	1	14.0
2 - Moderate	13	11.0	2	29.0
3 - Serious	7	5.8	3	43.0
4 - Severe	1	0.8	0	0.0
5 - Critical	0	0.0	0	0.0
6 - Maximum	0	0.0	0	0.0
Fatal	6	4.9	1	14.0
Totals	121	100.0	7	100.0

surprising, because the age range covered by this kind of restraint is much wider than that for Type B forward-facing child seats, let alone infant capsules.

There were 121 children in the study wearing lap/sash belts, with another seven for whom lap/sash belts were available but not worn. The distribution of maximum AIS among the non-fatally-injured, plus the number of fatally-injured children, is shown by belt use in Table 10.

Those wearing belts were evenly distributed through front passenger and the two rear outboard seating positions, as shown in Table 11.

Table 11 - Seating positions by maximum AIS, children restrained in lap/sash seat belts

	Maximum AIS							
Seating position	0	1	2	3	4	Fatal	Total	%
Front outboard left	5	29	5	1	0	1	41	33.9
Rear outboard right	4	23	2	3	1	3	36	29.7
Rear outboard left	1	26	5	2	0	2	36	29.7
Third row right	1	3	1	0	0	0	5	4.1
Third row left	0	2	0	1	0	0	3	2.5

Total	11	83	13	7	1	6	121	100.0

The ages of the 121 children using adult lap/sash belts ranged from one year to 14 (the sample maximum), with a mean age of nine. Of the 121, 21 (17.4%) were aged five years or less, and would probably have been better served by a child restraint or a booster seat in combination with the adult belt. However, there was no statistical relationship demonstrable between age and injury as represented by maximum AIS or ISS. Of the 21 children aged five or under, five (24%) sustained a maximum AIS 2 or more injury; among children aged six to 14, 22 out of 100 (22%) were AIS 2 or more. Thus, for this sample as a whole, even children aged under five years appear to receive as much benefit from adult belts as older children.

Six (5.0%) of the children using available lap/sash belts were killed, 21 (17.4%) suffered injuries with a maximum AIS of 2-4, and the majority (94, 77.7%) had injuries of AIS 1 or were uninjured. Although few of the children in the study for whom only a lap/sash belt was available rode unrestrained, as can be seen their chance of death or serious injury was much higher: the distribution of injury is significantly ($p<.01$) different from the distribution of injury among the restrained group.

Contact points for the two principal injuries among children restrained by lap/sash belts are shown in Table 12.

Table 12 - Contact points for two principal injuries: children in lap/sash seat belts

		Point of contact							
	Body region	Seat belt	Wind-screen	Dash panel	Door/ window	Car seat	Glass	External to car	No contact
First injury	Head		1	2	5	1	1	1	
	Face		1	4	7	1	3		
	Neck	3	2						5
	Thorax	9				1			
	Abdomen	3			2				
	Extremities	1		1	6	4	2	1	
	General	14			1	1	1		1
Second injury	Head				1	1			
	Face			1	3		1		
	Neck	2							1
	Thorax	1		1					

	Abdomen	7							
	Extremities	1		1	4	4		1	
	General	7							
Totals		48	4	10	26	13	8	3	7

FIGURE 16 - A restrained three-year-old died in the front passenger seat and the driver was also killed; however, a nine-year-old and a five-year-old wearing lap/sash belts in the rear survived with belt bruises (9512)

The youngest child to be killed when wearing a lap/sash seat belt was riding in the front seat of a 1982 Toyota Cressida that ran heavily into the side of an oncoming out-of-control Sigma on a country road, and after the crash ended up on its side (Figure 16). The Sigma caught fire as a result of the crash, and the fire spread in part to the Cressida. The child was a boy aged three years and eleven months (9512). The ΔV was some 65 to 70 km/h. The child suffered maximum internal thoracic and abdominal injuries, plus a fractured cervical spine at C1/C2. The female driver of the car was also fatally injured, with a fractured skull and internal abdominal injuries.

There was considerable distortion rearwards in the region of the A pillar on the passenger side. There was some indication that the child's head hit the windscreen, which had a bloodstained contact point. There were also contact points on the lid of the glovebox. The seat belt showed evidence of heavy loading, unusual with a light child, and it is likely that the internal injuries were inflicted by the belt, possibly as he was partly ejected out of it. The crash was survivable in the absence of contact with internal surfaces, as shown by the fact that a restrained five-year-old girl (9513) in the rear left seat suffered only minor concussion and belt bruising, and a nine-year-old girl (9514) in the right rear seat received only belt bruises.

This crash was the only one in which a child was killed in a frontal crash while wearing an adult three-point belt.

Four of the six crashes in which lap/sash-belted children were killed were side impacts associated with intrusion on the side the child was sitting, and the other was a rollover. In two of the side-impact crashes, the intrusion was very extensive and the crash probably unsurvivable in the child's seating position.

FIGURE 17 - Heavy side impact, restrained eleven-year-old sitting adjacent to intrusion and killed; nine-year-old in right rear seat survived (1114)

In the first of these two, an eleven-year-old girl (1114) was in the left rear seat of a 1981 Toyota Landcruiser (Figure 17). The car drifted off the left side of a country highway, came abruptly back on to the road surface and spun into the path of an oncoming van which hit at about 60 km/h. A 70-year-old female sitting next to her in the centre rear position was also killed, as was the adult male in the front passenger seat. A nine-year-old girl in the right rear seat (1116) survived with internal injuries. In the other case involving gross intrusion, an out-of-control utility truck impacted the left side of an oncoming Toyota Corolla at over 60 km/h. In the left rear seat was a 13-year-old boy (20823) who was killed immediately as a result of multiple skull fractures and brain tissue disruption.

FIGURE 18 - Five-year-old killed in rollover, ejected from rear window; improperly restrained while lying down and using only the lap part of a lap/sash belt (913)

Another death resulting from intrusion resulting from a side-swipe collision with a tree was that of a 13-year-old boy (6011) who was sitting in the right rear seat of a 1989 Holden Commodore. Although the intrusion was not severe, the collision was at high speed and the impact sufficient to cause fatal chest injuries. Rather similar damage was caused to a 1971 Volkswagen 1500 Fastback sedan in a side-swipe collision with an oncoming panel van. A girl aged seven (28111) was seated in the right rear position, adjacent to the maximum point of intrusion, and she died from very severe head injuries. In this case there was conflicting evidence about belt wearing, as the car was carrying six people plus the driver, and the age of the vehicle made any loading marks on the well-worn seat belts impossible to detect. In any event, the configuration of the crash made that seating position probably unsurvivable whether a seat belt was worn or not.

The only other death among children restrained by lap/sash belts occurred to a five-year-old boy (913) who was ejected from the lap/sash belt in the right rear seat of a 1991 Toyota Landcruiser (Figure 18). Sadly, the child had shortly beforehand been using a booster seat in association with the restraint, but the booster was taken away to allow him to lie down on the rear seat, with effectively only the lap part of the restraint holding him in place. This was insufficient when the Landcruiser rolled after hitting a roadside rock face on a country highway, and he was ejected through the rear window of the vehicle. Two adults in the car, plus an eighteen-month-old girl in a child seat, all survived. The roof of the vehicle was distorted to some extent, but survival space was generally sufficient for all occupants.

Some very small children using lap/sash belts in high-speed crashes received only minor injuries. The youngest was a one-year-old boy (3214) in the left rear position of a 1981 Ford Cortina that rolled in a single-vehicle crash on an open country road. There was extensive external damage to the car, and some distortion of the roof. However, both the one-year-old boy and his three-year-old sister (3215) escaped with minor bruising. A female adult sitting between them, restrained by a lap-only belt, died as a result of fracture dislocation of the cervical spine and disruption of the spinal cord, most probably as result of contact with the roof of the rolling car.

A girl aged two and a half (12211) was in the left rear seat of a 1990 Daihatsu Charade (Figure 19) that crashed head-on with a Nissan Patrol four-wheel drive. She suffered soft tissue neck injury that required admission for exclusion of cord injury, plus belt bruising on the left shoulder and both hips, but no more serious injuries. The restrained female driver sustained lacerations to the head and left knee, and a small child in a forward-facing child restraint (12212) was unhurt. The ΔV was about 55 km/h.

A slightly older child, a girl aged four (22412), survived a high-speed head-on crash in a Mitsubishi Sigma, with a ΔV of about 65 km/h, while seated in the front passenger seat. She received belt bruising only. The female adult driver suffered fractured facial and leg bones.

Some older children also survived very destructive crashes in lap/sash belts. For example, there were two 10-year-old girls riding in a Mitsubishi Colt hatchback (Figure 20) that came in to head-on collision on a country road with an oncoming Mazda RX7.

FIGURE 19 - Girl aged two in the rear seat of this Charade, wearing an adult belt, sustained soft tissue injuries only (12211)

The ΔV was 65 to 70 km/h, and the driver of the Colt died from unsurvivable chest and closed head injuries. The child in the front passenger seat (522) suffered no more than belt bruises, leaving loading marks on the webbing. The child in the rear (523) did suffer abdominal injuries, but was discharged from hospital within three weeks.

A Toyota Tarago "people-mover" was involved in a head-on crash with a truck at a ΔV of at least 60 km/h together with very extensive damage (see Figure 11, page 64). In the third row of seats were riding, in the outboard positions, an eight-year-old girl (28215) and a ten-year-old girl (28216). Both were wearing the available lap/sash restraints. Also in the vehicle were three adults and a three-year-old boy in a child seat with harness (28214). All three adults were killed, and all three children survived.

An older-style 1985 model Toyota Tarago drifted across to the wrong side of a country highway and hit a tree in the dead centre of the front of the vehicle. The ΔV was in the order of 60 km/h (Figure 21). The male driver suffered head injuries and fractured limbs, and the female front-seat passenger also received lower leg fractures. The vehicle was filled with eight children, in addition to the two adults in the front seats. Some of these children were unrestrained and lying on the floor, but four were wearing lap/sash seat belts. All suffered bruising from belt loading, and loading marks were apparent on the webbing. In addition, three of the children sitting in the outboard positions in the second and third row of seats - a male aged 13 (13612), another male aged 13 (13611), and a female aged 13 (13616) - received fractures to the limbs adjacent to the interior.

FIGURE 20 - High-speed frontal collision; driver killed, but children wearing lap/sash belts in front and rear survived with minor injuries (522)

In addition, a female aged 13 (13615) sitting in the left outboard seat in the third row suffered a traumatic amputation of her left arm. The mechanism of this injury was not clear. The occupants in this crash survived the high deceleration loads but were injured by contact with the generally unyielding interior of this particular vehicle.

In yet another high-speed crash involving a carload full of children, a 1989 Toyota Landcruiser carrying two adults and five children slid off a dirt road and hit a tree at an angle that drove it into the left side of the car from the front left towards the vehicle's centre. The male adult in the front passenger seat was fatally injured, receiving chest and other critical injuries from the intruding tree. The female driver was injured by contact with the steering wheel and surrounding components. A 12-year-old female (7015) wearing a lap/sash belt was seated behind the front-seat passenger, and her pelvis was fractured from contact with the vehicle interior. A 16-year-old wearing a lap/sash belt in the right seat behind the driver was not significantly injured, with abrasions only. The remaining children were wearing lap-only belts, and will be described in the next section of this report.

FIGURE 21 - Tarago carrying eight children and two adults; injuries from contacts with the interior of the vehicle (13611)

The only lap/sash belt-induced injury more than minor (AIS 1) was an AIS 2 haematoma of the liver received by an eleven-year-old male (18813) in the left rear seat of a 1972 Holden Torana. The ageing car did not have a retractor reel for this seat belt, and it is likely that the heavy belt loadings the boy received were as a result of wearing the belt rather loosely. The impact was dead centre front into a telegraph pole, ΔV in the order of 45 km/h.

As already noted, significant injury in the sample as a whole was more likely to be associated with side impacts than other configurations of crash. However, children wearing lap/sash belts survived some serious side impacts when seated away from the impacted side. Having gone through a red light, a 1990 Ford Falcon was hit heavily on the driver's side door by a bus at a crossroad, and the driver was killed. The ΔV for the Falcon was around 50 km/h. A 14-year-old boy (28612) and a 10-year-old girl (28611) were in the front and rear left seats respectively, and suffered minor injuries only.

On the other hand, sitting adjacent to the impacted side in a pure side-impact collision was far more likely to result in injury. There were 14 seat-belted children injured (maximum AIS 2 or more, including fatals) in side impact crashes; eleven of the 14 were seated on the side of the main impact.

Lap-only seat belts

Wearing lap-only belts were 35 children, and another five children were recorded as having been sitting in a centre seat but not wearing an available lap-only belt.

Four children wearing lap-only belts were in centre front seats, 23 in the centre rear, and eight children were in the third row of multi-passenger vehicles (six of these in outboard positions).

Table 13 - Maximum AIS, by whether lap-only belt used

	Lap belt worn		Lap belt not worn	
MAIS	Number	%	Number	%
0-None	5	14.0	0	0.0
1 - Minor	21	60.0	3	60.0
2 - Moderate	3	8.6	0	0.0
3 - Serious	2	5.7	0	0.0
4 - Severe	1	2.9	0	0.0
5 - Critical	0	0.0	0	0.0
6 - Maximum	0	0.0	0	0.0
Fatal	3	8.6	2	40.0
Totals	35	100.0	5	100.0

The ages ranged from two to 14, with a mean of between eight and nine. Eleven were aged 0 to 5 years, indicating that they were very small to have been restrained in any kind of adult belt. Eleven were aged 6 to 10 years, and 13 aged 11 to 14 years. Males and females were evenly distributed.

Injuries (maximum AIS for each case), categorised by whether an available lap belt was worn, are shown in Table 13. As was generally the case for the other restraints, the injuries suffered by the children were mostly of a minor nature (21 out of the 35 restrained, or 60%). Five of the children attending hospital after a crash when restrained in lap-only belts had not been injured. Three restrained were killed, and two of the unrestrained while in seats for which lap-only belts were available, but because of small cell numbers the difference in injury distribution between restrained and unrestrained is not statistically significant.

Relating maximum AIS to age, two of the 11 children aged five or under received AIS 2+ injuries (18%), and seven of the 24 aged six and over (29%). However, the cell sizes are too small to read any significance into these figures.

Contact points for the two main injuries for each injured child wearing a lap-only belts are shown in Table 14.

Table 14 - Contact points for two principal injuries: children in lap-only seat belts

		Point of contact							
	Body region	Seat belt	Console	Dash panel	Door/ window	Car seat	Roof	External to car	No contact
First injury	Head		1			4	1	1	
	Face		1		1	3			
	Abdomen	4							
	Extremities		2	1	1				
	General	1							1
Second injury	Spine	1						1	
	Thorax	1							
	Abdomen	4							
	General					1			
Totals		11	4	1	2	8	1	2	1

The main differences between this table and Table 12, which showed contact points for children restrained in lap/sash belts, are in relation to abdominal injuries and injuries to the head/face region. Seat belt-related abdominal injuries are much commoner among lap-only belt users (eight out of 35 children, 23%, as opposed to 10 out of 121 lap/sash belted children, 8.3%). This difference is statistically significant ($p<0.02$). Injuries to the head and face occurred to similar proportions of the lap-belted and lap/sash-belted children, and the incidence of injuries overall did not significantly differ between the two types of belt system. However, contacts against the vehicle structure among the lap-belted children predominantly involved structures facing them such as the car's front seat and the console, whereas the heads of the lap/sash-belted children more commonly hit the doors and windows beside them. If the torsos of the lap-belted children had been restrained to restrict movement of the upper body, many head injuries would have been prevented because in three-quarters of the cases the child was in a centre seating position.

There were three fatalities among lap-belted children.

One of the children killed (20013) was a girl aged five and a half restrained in the centre rear seating position of a 1986 Toyota Cressida (Figure 22). Coming off a suburban medium-speed highway, the car hit a telegraph pole in the centre of the front of the car, with a resulting ΔV of 40 to 45 km/h. Vehicle examination showed the lap belt to have been adjusted so that it would have been very loose for this child. Examination also showed the console between the two front seats to have been extensively damaged. In the frontal impact, the child received a pattern of injuries that is typical of lap-belt restraint in a frontal impact at more than a slow speed. She suffered minor facial injuries and some external leg injuries, probably from contact with the console. On the front and right and left sides of her hip were bruises and abrasions typical of lap-belt loading, and she had some associated internal haemorrhage between the bladder and the pubic symphysis. She died almost immediately from a fracture-dislocation of the second and third cervical vertebrae with associated cord damage, and the detail of the injury showed that this injury was caused by stretching (distraction) of the neck.

In brief, this child was allowed to move forwards to an excessive extent by the loose lap belt, thus allowing head and face contact with the console in front of her. She flexed violently over the lap belt, causing the bruising in the hip region and intra-abdominal injury. In the flexed position, her head was stretching the spinal cord as a result of the forces of deceleration, and this fact - in association, probably, with the relatively insignificant head contact - cause the distraction fracture-dislocation of the neck that was the fatal injury.

This was a survivable accident, giving rise only to moderate deceleration from the change of velocity. The driver suffered some lacerations to his face as he hit the windscreen, and a 13-year-old girl in the left outboard seat, in a lap-sash belt, suffered cracked ribs and bruising from belt loads.

FIGURE 22 - Pole impact with fatal neck injuries to girl aged five restrained by centre rear lap-only belt; others in car suffered lacerations and minor injuries from belt loadings (20013)

Another death was an eight-year-old female (23216) who was seated in the outboard left seat of the third row of a light passenger-carrying van (a 1983 Holden Shuttle). The vehicle left a country road and rolled down a six-metre embankment. The damage to the vehicle indicated that during the roll the vehicle hit heavily on its left side towards the rear, causing some intrusion directly adjacent to the deceased child's seat. The girl died from severe pulmonary contusion (bruised lung) affecting all parts of both lungs, probably in association with the vehicle damage in the region. Another child in the same vehicle, an 11-year old male in the outboard right seat in the third row, also wearing a lap belt, also suffered chest injuries that were not fatal.

In a crash that was essentially unsurvivable in the child's seating position, a 1975 Toyota Corona left an outer suburban road at high speed and half-rolled into a telegraph pole so that the pole deeply intruded into the roof of the car. A 13-year-old boy (19911), in the centre rear position, died of multiple skull and facial fractures, with associated brain damage.

Among those non-fatally injured in frontal crashes, in a very severe crash a girl aged 12 years (7411) was seated in the centre rear position of a 1983 Holden Statesman. The car drifted over to the wrong side of a country highway and collided head-on with an oncoming semi-trailer. The ΔV was in the order of 75 to 80 km/h, and the car ran some way underneath the truck. Both adult front seat passengers were killed. The girl was wearing a lap-only belt, and received several facial fractures from contact with the console structure in front of her, and internal abdominal injuries from the lap belt. Her 18-year-old brother, in a lap/sash belt in the left rear position beside her, sustained minor chest and abdominal injuries from belt loading.

In the 1989 Landcruiser that hit a tree, to which reference has already been made, there were three children restrained by lap-only belts. A male aged 14 (7013) was in the centre seat of the bench immediately behind the front seats. He suffered moderate head and spinal injuries. In the third row of seats, another bench, were seated a 12-year-old boy on the left (7014), and a 13-year-old boy on the right (7016). The first, seated adjacent to the intruding tree, suffered fractures to the skull and cervical spine. The other, seated away from the intrusion, received only left-side abrasions.

A 1989 Nissan Skyline collided with a cliff face at the side of the road. Three children were on the back seat, all restrained in available belts. The driver and the two children seated in the outboard rear positions (one a one-year-old in a child seat) received minor belt bruising only; the six-year-old boy (28713) in the centre rear position, however, was admitted to hospital with injuries to the bowel. The belt was apparently correctly adjusted.

A 14-year-old male (1112) was seated in the front centre passenger seat of a Toyota Landcruiser that was struck on its left side by an oncoming van, causing severe intrusion damage. He suffered internal abdominal injuries. Two adults (left front and centre rear) and a child (left rear) died in this crash.

UNRESTRAINED CHILDREN

There were 19 children in the study who were known not to have been restrained at all in the crash. Five of these children were fatally injured, a far higher proportion than among the restrained children. In fact, as might be expected, the risk of a child coming into the study with a serious (AIS >2) injury was far higher if unrestrained (see Table 15).

Table 15 - Maximum AIS, by whether any restraint used

	Restrained		Not restrained	
MAIS	Number	%	Number	%
0-None	44	19.3	0	0.0
1 - Minor	135	59.2	6	32.0
2 - Moderate	23	10.1	3	16.0
3 - Serious	10	4.4	5	26.0
4 - Severe	2	0.9	0	0.0
5 - Critical	2	0.9	0	0.0
6 - Maximum	0	0.0	0	0.0
Fatal	12	5.3	5	26.0
Totals	228	100.0	19	100.0

These two distributions of injury differ very greatly, to an extent that is highly statistically significant.

A brief description of the unrestrained fatalities follows.

The youngest of the fatally-injured unrestrained children was a four-month-old boy (19812) who was being cradled in the arms of his mother in the right rear seat of a Mazda 323 hatchback (Figure 23). Going through a suburban intersection the car was hit on its left side by a station sedan at an impact speed of less than 20 km/h. After the impact the Mazda rolled 360 degrees and back on to its wheels. During the roll the child was ejected through the broken back window of the hatch, and died soon after with head injuries. Neither the driver nor the mother were injured.

Another child being held in an adult's arms (222) was in the front seating position of a Holden hatchback that ran into the side of an out-of-control oncoming Corolla on a country road. The front-seat adults in the car suffered no significant injury, but the child was killed as it struck the dash and windscreen surrounds.

FIGURE 23 - Mazda hit on side and rolled; adults uninjured, but baby being cradled in arms of mother in right rear seat ejected through rear hatch and killed (19812)

A four-year-old female (312) was riding in the right rear seat of a Mitsubishi station sedan that left the road on a sweeping bend on a country road and rolled twice. The child was ejected through a broken window and probably died on hitting a table drain. The crash also resulted in the death of the unrestrained female driver, but five other unrestrained occupants escaped without serious injury.

Another ejection was in the case of a seven-year-old girl (28411). She was riding in the centre rear position of a 1982 Subaru station wagon, unrestrained, sleeping with her head on her father's lap. The driver apparently fell asleep, and the vehicle hit an embankment and rolled several times. The child was ejected and thrown about 30 metres, resulting in highly destructive head injuries. Other passengers in the car were not significantly injured.

A 1968 Ford Falcon abruptly turned across the front of an oncoming semitrailer in the outskirts of a country town. The truck impacted the car at some 55 to 60 km/h, and this resulted in almost total destruction of the left side of the Ford. The adult front-seat (unrestrained) passenger was ejected and killed immediately, as was the unrestrained left rear passenger. However, the unrestrained driver survived without significant injury. In the rear seats of the car were two children. A seven-year-old girl in the centre rear position died (10214) within two days from a closed head injury and lung contusions. An eight-year-old boy (10215) was also unrestrained; he was ejected from the wreck and found about five metres away, but escaped with upper limb fractures.

There were two other cases in which non-fatal injury occurred in children who were sitting, otherwise unrestrained, in the arms or on the lap of an older person. In one of these, a male aged eight (811) was sitting on the lap of a restrained, older child in the front passenger seat of a Ford Falcon. In a left-frontal collision with an oncoming passenger car at a ΔV of over 50 km/h, the child was thrown into the windscreen and left A pillar, resulting in serious head, chest and limb injuries. The restrained adult front-seat occupants were not injured. In the other case, a six-month-old baby boy (1714) was being held of the arms of his mother in the right rear seat of a 1979 Toyota Corona that turned across the front of an oncoming car on an urban street and was hit on the left side. The child ended up on the floor of the car but escaped with facial bruising.

There were three unrestrained children in a 1985 Toyota Tarago that hit a tree, a crash to which reference has already been made above in the context of children restrained by adult belts. In this vehicle, a four-year-old girl (13613) and a girl aged seven (13614) were lying in the space behind the third row of seats. Both probably impacted against the rears of the seats in front of them and as a result the seven-year-old received a ruptured liver; the other child escaped with bruises. Yet another child, a six-year-old girl (13619), was unrestrained between the second and third row of seats. She was concussed, possibly as a result of being thrown into the windscreen.

MISUSED CHILD RESTRAINTS

There were seven cases of serious misuse of a child restraint. Six of these were associated with poor fitting and/or use of a forward-facing child seat with harness (Type B), and the others were a baby capsule and a booster seat. The numbers are small, but these figures indicate that among all Type B child seats coming into the study, 16% (six out of 37) of cases were associated with misuse, as were one out of six capsule-restrained cases, and one out of 24 booster seat cases.

This does not mean, of course, that this is a rate of misuse typically found in the community, because in an injury-based sample such as this, a child is more likely to be included if misuse is associated with injury. Roadside survey data in New South Wales indicate a rate of "incorrect" use of child seats of around 8% (Road Safety Bureau, 1994).

Five of the children concerned were aged six months or less. In two cases the injuries were fatal, in one case critical (maximum AIS 5) and in another two cases moderate (maximum AIS 2). Two children escaped with no or minor injury. In all but one crash the main impact was frontal or near-frontal.

Thus, five of the seven misuse cases (71%) were associated with AIS 2+ injury. There were 55 cases of children using any kind of child restraint without evidence of serious misuse; only nine of them, or 13%, suffered an AIS 2+ injury.

One of the fatalities was associated with serious misuse of a booster seat, and has already been described. The death was of a three-year-old girl (18412), restrained only by a lap belt on a soft booster "chaise", with its own seat back, in a frontal crash against a tree at over 70 km/h. Having flexed over the lap belt, her head contacted the structures in front of her and caused a distraction (stretch) fracture dislocation of her cervical spine. A booster seat is designed to be used only with a lap/sash belt, and may be dangerous in the absence of upper torso restraint.

The other fatal case has also already been described. This was the two-year-old boy (22413) in a Type B child seat in the rear of a Mitsubishi Sigma that also hit a tree at high speed, 65 to 70 km/h. The harness of the child seat was not used, and the boy and the seat were restrained together by an adult belt that caused fatal neck injury to the child.

A critical head injury was sustained by a five-month girl (13413) in a Type B seat in the left rear position of a small sedan (a 1993 Suzuki Swift). Following a rear-end impact, the child's head impacted structures in front of her, with excessive excursion of the child's torso being facilitated by the routing of the lap portion of the lap/sash belt around the base of the seat. Further, the top tether strap had not been employed.

In another case in which the top tether of a Type B seat had not been employed, a female child aged seven months (423) was restrained in the rear right seating position of a Holden Camira that was hit on the right side by a truck. The child sustained head injuries, but the extent to which this resulted from excessive excursion is difficult to estimate. This particular design of restraint offered little protection to the head in side impacts.

And in yet another case of non-use of the top tether, in a minor frontal crash a child (6912) in a Type B seat in the centre rear position swung down and forwards and sustained unnecessary facial injuries by contact with the centre console.

A one-year-old girl (12212) in the right rear position of a Daihatsu Charade that crashed head-on with a Nissan Patrol four-wheel drive (ΔV about 55 km/h) was restrained in a Type B seat. She was not injured, showing that child restraints may be tolerant to "minor" misuse. In this case the seat had been installed with the shoulder part of the lap/sash belt routed in front of the seat structure and behind the child, as the father of the child was convinced that this would result in a more secure system than the standard use of a top tether.

A baby capsule in the rear centre position was incorrectly installed in the case of a male infant (122) aged six days. The Ford Meteor was involved in a collision and then rolled. As noted earlier in this report, the infant was apparently dislodged from the restraint. It was found that the top tether strap had been correctly attached to the car. However, the lap belt had not been used to secure the body of the capsule, which therefore was grossly unstable in a crash and could fly around. Further, the body band that held the infant in the restraint was apparently loosely adjusted for the size of the child. In the same car, another child (123) in a forward-facing child seat received minor injuries, and later examination showed that the restraint harness in the seat had also been adjusted very loosely for a child of its weight and height.

7 DISCUSSION OF RESULTS

OVERALL OBJECTIVES

Nearly 20 years ago there was conducted in New South Wales an extensive program of work on the protection of children. The work included sled studies and the mounting of a series of in-depth follow-up crash investigations of crashes involving children as passengers. It was found that child restraints complying with the original (1970) Australian Standard offered good protection, even in high-speed crashes. Fatal injuries were only associated with intrusion of the occupant space. Neck injuries were not shown to be a significant problem.

Since then, many international studies have confirmed the overall effectiveness of child restraints, and of lap/sash adult belts used by children. However, clinical studies in some countries have raised doubts about the injury-reduction potential of some kinds of restraint in some kinds of crash. In particular, fears about neck injury and the documented success of rearward-facing restraints in the Scandinavian countries have caused many analysts to re-examine the whole question of forward-facing restraints for children, especially young ones.

Thus, one of the main objectives of this present study was to determine whether there had arisen in recent years any substantial or common problems with child restraints as approved by Standards Australia, given a much higher rate of use in recent years, the evolution of child restraint design, and the mandating of anchorage points for top tethers in Australian cars.

The indications are that this has not been the case. The vast majority of children in the study who were restrained in child restraints suffered only trivial or minor injury. Indeed, this study has confirmed that a child restraint is an exceedingly effective piece of safety equipment, and that the human child is a very resilient animal.

THE STUDY IN PRACTICE

The design of the study was such that the focus was on child injury. Given that it was not practicable to establish an on-scene study with a call-out team on standby, the study thus depended on notification of injuries suffered. This was possible because most injured children attend a hospital emergency department and are seen by emergency personnel. In addition, all fatal and most other injuries are recorded on the routine police accident report form. These forms were not in practice used for data analysis because of privacy restrictions.

However, because our definition of "injury" was not restricted to admission to hospital, several child cases came into the study having suffered only very trivial injury. This uncovered some astonishing cases of survival in very severe crashes. It is highly likely, therefore, that there were many other unknown cases of survival without injury in severe crashes, that did not come to our notice because of the restrictions of the notification system. These cases would never come to any official notice because nobody - among police or ambulance personnel, hospitals, or the RTA - ever knows they exist, or if they do know, routinely records that existence.

There does exist in New South Wales the Road User Protection Equipment Performance (RUPEP) system. This is an informal arrangement between the RTA and the police and ambulance services, whereby individual cases of poor or good performance of restraints is brought to the attention of the RTA Crashlab. We became aware during the year of the study that the number of cases being notified through the RUPEP system comprised a tiny minority of the "interesting" cases that we were investigating. If, as seems likely, the police report form will never include details of uninjured passengers, there would appear to be a strong argument for strengthening the RUPEP system through more formal arrangements between the various administrations. It is essentially impossible to monitor the effectiveness of safety equipment without recording - either on a sample or routine basis - cases where injury did not occur.

During the course of the study we were exposed many times to the work of the Accident Investigation Squad (AIS) of the NSW Police Service in many parts of the state. Personnel of the squads were of great assistance to the CAPFA team. They have a high degree of expertise in investigating the causes of crashes, assisted by photogrammetric techniques and other sophisticated aids to drafting, site analysis and vehicle dynamics and defect detection. However, the work of the AIS is limited to investigation of crashes resulting in death or severe injury and which could result in the bringing of a serious charge against a driver. If a driver "at fault" is killed, the AIS has no brief to investigate anything. From a law enforcement point of view, this approach is entirely understandable. But from a road safety viewpoint, it seems a waste that this investigational expertise is thus constrained. With very little extra training and experience, these already skilled officers could provide invaluable information, on an essentially routine basis, on the consequences of severe crashes as well as their causes. The effect would be some diversion of resources away from legal retribution and towards prevention of injury by other means.

At another level, there are moves within the RTA to provide more investigational expertise to engineers and other employees in the various regions in the state.

These steps should represent a highly commendable move towards the routine provision of crash data that are not simply directed towards support of the legal system or the counting of injuries.

Many notifications were of crashes in country areas, where the severity of the crashes made for better differentiation of the effectiveness versus the ineffectiveness of restraints. For future work, it will be necessary (but more difficult) to concentrate on country areas for the most cost-effective collection of data.

Notes on ethical issues

In setting up the study, we did experience difficulties and some delays in obtaining approvals from the several ethics committees with responsibilities extending over the wide area of our catchment. These difficulties did not arise for ethical reasons - they related mainly to the need for detailed explanation of the methodology, as most members of such ethics committees have no experience in injury epidemiology. Where an ethics committee did include a specialist such as a child trauma surgeon, the difficulties were much less. In no case, except for some minor editorial amendments, did any ethics committee fail to accept our proposal in the end. But the correspondence and discussions took in some instances many months.

Later, we found it rather frustrating that government officials (such as those involved in RUPEP) had easy access to the same information as we were seeking, and that reporters were commonly writing in the papers about crashes that ethical constraints prevented our early investigation. In the most cumbersome arrangement (which of course covered every ethical consideration) once a child had attended an emergency department, a nominated person in the hospital then contacted the parents or guardians for their agreement that their names might be passed to the CAPFA team. Given that agreement, the team was notified of the parents' agreement. The team then contacted the parents and arranged for interview and to examine the vehicles. Given the difficulties in contacting uninjured adults, this usually took many days, and several cases were lost by this time. When it came time for the team to seek medical information on injury, confirmation that specific permission had been given for this was required.

It is stressed that in the overwhelming majority of cases the parents were exceedingly willing to provide every assistance to the team, often going out of their way to provide information we could not have obtained elsewhere, even when serious injury had occurred to their child. There was a slightly higher incidence of non-agreement to participate than in the Monash study of adult injuries reported by Fildes *et al*, and this might be a result of the requirement by some ethics committees - not all - that we stated that the information might be used in court proceedings. The Monash team were not required to make such a bald statement.

We well understand the need for ethical oversight of research, especially research involving children. And we were well aware of the heavy demands on the time of the ethics committees with which we dealt. But we believe that there is a good case for short-cutting approvals for, and easing restrictions on, epidemiological work that does not include invasive procedures. At the very least, the NSW Health Department could be empowered to grant a blanket approval covering the state as a whole. We would also like to see some protection from subpoena for data gathered purely for research, as is the case in some other states.

The vehicles

With respect to the design and construction of the vehicles in the sample, we found little of especial relevance to the effectiveness of restraints. For some cars, it had clearly been more difficult to fit restraints than others, and the newer vehicles are much better in this regard than the older. A few of the older cars had manually-adjustable (non-retractable) seat belts, and in a handful of cases the looseness of the belt had probably increased the severity of injury. In view of the phasing out of non-retractable belts in outboard positions many years ago, this is not a matter of high priority. However, the fact that most centre lap belts are manually adjustable is a matter of concern, and this will be discussed in the context of lap belts generally.

Rather to our surprise, we did not find that the average age of the vehicles in the sample was higher than for the vehicle population as a whole, although in both the sample and in the vehicle population most cars are over five years old.

All the vehicles in the sample had only a lap belt available for a child seated in centre seat. All else being equal, this is the safest seating position in a crash. However, all else is not equal because the occupant of this seat is provided with the least desirable restraint, even if it is much better than no restraint at all. Some Australian manufacturers, and some manufacturers of imported cars, are now providing a lap/sash belt in the centre rear seating positions. This is highly commendable. Much less commendable is the fact that most family cars on the market, even in the higher price ranges, are still only fitted with lap belts in centre rear seats. From July 1994 even new long-distance buses will be required to have lap/sash seat belts (which will be integral with the seats) in all seating positions, and it is hardly acceptable that any passengers in new family cars should be less well protected.

The most striking feature of the vehicles in the sample was the high proportion of cases contributed by crashes involving four-wheel drive and multi-passenger vehicles. Clearly, these were being used for their intended purpose: namely, to carry many people - including children - at a time. The effect, however, is that when one of these vehicles is involved in a crash, many people are simultaneously exposed to the risk of injury. The numbers are small, but a higher proportion of crashes involving these vehicles included rollover than for the sample as a whole, and rollover added to the risk of injury for both restrained and unrestrained children. Because of the relationship of centre of gravity to track width, many vehicles of this configuration are known to have a relatively high propensity to roll, and it is therefore even more essential that occupants, including children, are offered maximum protection within them.

Unfortunately, the structural configuration of these vehicles makes the fitting of upper-torso restraints and child restraints in all seating positions more difficult than in the conventional passenger sedan, and in our sample there were many children who suffered from this fact. It is a paradox that in vehicles which are so commonly used to carry lots of children that is comparatively difficult to restrain all of them effectively. It is highly desirable that as fast as possible relevant Australian Design Rules for occupant protection are extended to all passenger vehicles used for personal transport.

In the interim, a desirable measure would be the provision of guidelines that are acceptable to registration authorities for the retrofitment of lap/sash seat belts to older vehicles on a voluntary basis. At present, parents who might wish to improve the safety of their children by replacing lap belts with lap/sash belts are discouraged from doing so by the rigid application of the prohibition on altering safety equipment.

The prevalence of side impacts in causing injured to restrained children has been commented on in the context of the results. Side impact protection is presently a matter of current concern to manufacturers and regulatory authorities throughout the world, including those in Australia, and the difficulty of providing such protection will be manifest from some of the crashes described. Nevertheless, if side impact protection can be improved (either by attention to the sides of the vehicles or to the objects that contact the sides, including the fronts of other vehicles and roadside obstacles such as trees and posts), then there will be real benefits for restrained children because most of those restrained and injured have received their injuries from intrusion and contact with the car's interior surfaces.

It also follows that improved padding of interior surfaces could reduce the incidence of at least the minor and moderate injuries that result from contact. At present, there is little more than superficial attention paid to padding the parts of cars that occupants can hit. Children in the present sample commonly contacted the console between the two front seats, and the backs of the front seats. These are areas that are not padded in any useful manner.

While flying cargo did not emerge as a major safety problem in the present study, isolated cases of cargo causing injury are known to occur. In the study, cargo disrupted the mounting point for the top tether in one case, and may have contributed to the head injuries of a child in another. Cargo nets with suitable anchorages should be available for all station wagons, hatchbacks and passenger-carrying vans, at least as optional equipment.

Infant capsules

Few infant capsules appeared in our sample, a reflection of the comparatively few children who are carried in them and, probably, because their general level of effectiveness is high. It so happened that in our sample the only fatality occurring in a properly fitted and used child restraint was in one of these, but this involved a heavy side impact against which protection would have been exceedingly difficult in the most ideal of circumstances.

Even in these small number of cases we were aware of difficulties faced by parents installing and using these restraints. All the infant capsules in our sample used body bands to restrain the children, and with our experience we support the move (driven by recent amendments to the Australian Standard) away from the use of body bands with adherent material fastening and towards the use of harnesses, even given the difficulty of restraining an infant in a harness. We were conscious of the capacity of the child restrained in a body band to slide underneath it in a frontal or more complex crash, as probably happened in the instance of the fatality in this subgroup. Webbing shoulder straps should help to prevent this movement, but there is as yet not enough experience with them to know whether they are being used effectively. This is just the kind of monitoring that should be employed on a routine basis.

Forward-facing child seats

Because of the requirement that a child restraint must have a top tether, child restraints in Australia are almost universally fitted in the rear. This is not typical overseas, where child restraints are commonly used in the front passenger's seat. This allows the driver an easy view of the child. However, with the burgeoning popularity of airbags this has raised a serious complication. If the restraint is adjacent to the passenger-side dash panel, within which the airbag is commonly fitted, in a collision the restraint - and the child - will be impacted by the inflating airbag at a speed that can cause injury or even death. Accordingly, attention is urgently being paid to the necessity for warning parents who use restraints in such a manner, together with research to counter the problem and to determine tolerance levels (Weber, 1993).

This is not a problem that requires urgent attention in Australia, although when airbags become more commonly fitted for the front passenger it will be necessary to stress the importance of keeping any restrained children in the front passenger seats well in the seated position.

Just as the main reason that parents in some other countries prefer to be able to see their children's face when restrained in the car, and therefore place the rear-facing restraints in the front passenger seat, parents in Australia prefer to have restraints in the rear seats facing the front. The evidence is that parents use forward-facing restraints as soon as practicable; in our study, we never saw rearward-facing restraints used at anywhere near the maximum size of child permissible.

However, some overseas studies (reviewed earlier) have indicated that the use of forward-facing restraint with firm support of the upper torso can increase the risk of neck injury for children. It is commonly argued that the neck of the child is more vulnerable to injury in a crash than that of an adult in these circumstances because of the incompletely developed anatomy of the younger person. That is one reason why, all else being equal, a child (and for that matter an adult) is better facing rearwards in a crash than forwards, because the crash loads are spread along the length of the back of the body rather than concentrated in small areas. The issue, effectively, is this: does restraining the torso of a child who is facing forwards in a crash expose the child's neck to an unreasonable risk of injury?

Many research workers have therefore studied the incidence and mechanisms of neck injury in restrained children. For example, as noted in the literature review in earlier sections of this report, Agran *et al* (1987) found that there was an increase in neck injuries with increased (adult) seat belt use among children, particularly those aged 10-14 years of age. Norin *et al* (1984), using a sample of seat belted children in Sweden, reported a slight increase in minor and moderate neck and chest injuries from the forces of the belt.

Available data show that in the absence of head contact, serious cervical spine injury among infants and children using restraints or child safety seats is rare, although several individual reports are in the literature (Huelke *et al*, 1992; Planath, 1992). The matter has been the subject of much research, stimulated by individual cases of this kind (Langweider and Hummel, 1989; Stalnaker, 1993; Weber *et al*, 1993; Janssen *et al*, 1993).

Unfortunately the literature is not always explicit on how the restraints have been installed in the cars. Without a top tether or firm shoulder strap, they can tip forwards and allow axial loading of the neck. Fractures of the cervical spine among children, in the absence of head contact, have been used as the basis for work on the determination of neck injury criteria (Weber *et al*, 1993; Trosseille and Tarriere, 1993). It is perfectly valid to do so, but account should be taken not only of rare crashes in which children's necks have been injured but also those in which injury has not occurred, even at high levels of ΔV in frontal crashes.

Child restraint systems prevent more severe injuries to other parts of the body than the neck, and as originally identified by Huelke (1977), an increase in minor neck injuries is associated with a *decrease* in severe and fatal head injuries when lap/sash belts are used. This is because the prime benefit of upper-torso restraint, just as is provided by the sash part of an adult seat belt or a child restraint harness, is prevention of the upper torso swinging forward and in other directions (excursion) in response to crash forces. Further, without a top tether child restraints can tip forwards and thus still allow axial stretch (distraction) loading of the neck.

A study of this kind could not, of course, be expected - except by pure chance - to uncover a rare event, such as cervical fracture without head contact. It was aimed at examining *typical* events. Therefore, we spent the entire year of data collection alert for neck injuries in small children, and failed to find any in the absence of direct head/neck contacts. Several children of around two and three years of age rode out extremely severe frontal crashes without neck injury. These were crashes with forces towards the limits of survival for any restrained human, and the children rode them out at least as well as - and generally better than - the adults in the same cars.

Taking only cases involving children (all under three and a half years of age) restrained forwards facing in "Type B" child restraints with shoulder harness and top tether, there were four in frontal or near-frontal crashes with a ΔV conservatively estimated after damage measurement of at least 60 km/h who received no significant neck or other injury. Another five similarly escaped injury in frontal crashes with a ΔV in the range of 50 to 60 km/h. The only case of neck injury, and the only severe injury in this group, was associated with gross misuse involving the replacement of the child's shoulder harness with the sash part of the adult belt.

There was no statistical relationship between ΔV and injury among these children, although the numbers are small. This indicates that when children are injured in Type B child restraints, it is more likely to be a result of intrusion, contact with nearby parts of the vehicle's interior and other occupants, invasion of the child's space by collapsing seat backs, flying glass and other such mechanisms than it is from the forces of deceleration.

A recent injury-based follow-up study of 198 children, using police and hospital data and covering a four-year period in New York, came to essentially identical conclusions (Kelleher-Walsh *et al*, 1993). These authors found a predominance of facial injuries, plus a lesser incidence of head injury.

It follows that invasion of the child's survival space by failures such as seat-back collapse is a mechanism of injury that requires further attention. Seat backs should simply not be able to collapse in the type of low-speed rear-end collision that was uncovered in this study.

It also follows that an important feature of child restraints is the extent to which they offer protection for the sides of the head. Even casual observation will show large differences in this capacity at present. This is not a matter that is specifically addressed by the Australian Standard.

Neck (and other) injuries only occur and come to light to clinicians, of course, when the restraint system has failed to protect against crash forces. Usually unrecorded are instances when no injuries have occurred because the restraint has been effective, despite very high crash loadings. This is a point of which we have already made mention.

It did appear that parents tend to move their children out of dedicated child restraints too early. The oldest child restrained in a forward-facing Type B seat was three and a half, and only three weighed as much as 15 kg. Given the very high protective capacity of these restraints, parents should be encouraged to use them until the children the child approaches the maximum approved mass, or is manifestly too big for the seat. Our data show that many children injured when using adult seat belts were too small, although they undoubtedly received benefit from such use. Indeed, it is probable that a well-fitted adult three-point seat belt will provide better protection than a poorly-installed or badly adjusted child restraint.

Rearward-facing child seats

The understandable reluctance of parents to have children other than infants restrained rearward-facing in the rear seat (not to speak of the reluctance of older children themselves) is manifest by the young ages of the children in the study restrained in these "Type D" seats. All the four children were under six months, and convertible seats were turned round as soon as possible. This is despite the fact that rearward-facing seats are approved for children of up to 18 kg, or about five years of age. Whatever the theoretical benefits of rearward-facing seats for children beyond the infant stage, in Australia at least it must be accepted that children will be restrained facing forwards.

Of the small number of children in the sample in Type D seats, one did sustain a head injury in a rollover that might have been prevented if he had been restrained in the centre of the rear seat, rather than in an outboard position.

Booster seats

The use of a booster seat provides a useful transition between a child restraint and an adult belt. We found that booster seats are generally very effective, and in the sample there were two cases of survival of three and four-year-old children in high-speed and very destructive collisions when so restrained.

Unfortunately, the booster seat is open to a very dangerous form of misuse:

namely, the use of the booster with a lap belt alone. Although seats carry warnings about this misuse, which is contrary to regulations, it is understandable that many parents who find instructions confusing or illegible have no idea of its danger. This is compounded by the popular (and, all else being equal, correct) view that the centre rear seat is the safest. But all else is not equal, because in the vast majority of cars the centre rear seat only has a lap belt supplied.

Lap/sash seat belts

Although there is still some concern about small children using adult restraints, this study has confirmed earlier findings that children - even very small ones - do surprisingly well in severe crashes when using lap/sash seat belts. As was the case for child restraints, we did not find neck injury to be a problem.

The prime cause of injury among children restrained by an adult three-point belt was contact with the interior surfaces of the car, often in association with intrusion. One of the main benefits of dedicated child restraints with top tethers is that they can be mounted away from the side walls of the vehicle, thus minimising the risk of intrusion injury.

For an adult belt to be effective, of course, the child must be properly held within it. We did not find a form of performance degradation that is often suggested (for example, Agran and Winn, 1988): namely, resulting from the wriggling and restlessness of the active child. To the extent that occurs, it did not appear to affect protection to a significant extent; indeed, it should not, because an adequate restraint should be tolerant of minor "misuse". We did find, however, deliberate degradation by some adults allowing use of the lap part of the belt on its own. This resulted in the death of at least one child. Further, while as already noted the number of cars with manually-adjustable seat belts is these days very small, we did find one case of belt-induced abdominal injury in a child restrained in a manually-adjustable lap/sash belt that was being worn too loose. A substantial benefit of the retractor reel is that it keeps the webbing in reasonable proximity even to the restless child.

Lap-only seat belts

Although the use of lap-only belts prevented many children in our sample from more serious injury, the evidence of this study is that the lap belt is an incomplete restraint, to be used only when no better system is available. There was a significantly greater incidence of belt-induced abdominal injury among lap-belt wearers than lap/sash users, which supports the conclusions of Lane (1992) that the child in the centre seat with a lap belt is at significantly greater risk of seat-belt induced injury. The incidence of injury to the head and face was much the same among lap-belted and lap-sash belted children, but because those wearing lap belts were using centre seats many of these head injuries should have been preventable because upper torso restraint would have minimised the forward excursion that allowed contact with structures in front, such as consoles and front seats. This finding is in accord with that of Tingvall (1987), who found no difference in injury rate between children restrained by lap belts in the "safer" centre seat than in outboard seats with three-point belts.

In addition to the general inadequacy of the lap-only belt, there is the additional factor that in Australian cars (unlike the typical American car, where lap belts are much more common and lap belts have retractors) the lap belt is almost always manually adjustable only. This compounds the problem of misuse by too easily allowing the belt to be worn loosely and thus increasing the risk not only of abdominal injury but also head injury through excessive excursion of the torso.

The movement of some manufacturers, including major Australian ones, away from the use of centre lap belts and towards lap/sash belts is to be commended and strongly supported, and there can be little excuse for the many manufacturers - even of some luxury cars - that continue fitting these inadequate restraints in the very positions that children are most likely to use them.

Unrestrained children

While observation in any city street shows that children often ride in the arms of adults, the number of such children who received serious - including fatal - injuries in the present sample is still of great concern. There were six definite cases of this occurrence, and one doubtful but probable. All were crashes in which a properly restrained child would probably have escaped injury. Tragically, the child is being held this way with its interests at heart, with the best will in the world.

Many of the children were probably sleepy, requiring rest and comfort. It was not part of our program to investigate the causes of crashes, but simply their consequences. However, it was striking that many of the crashes involving children in arms were attributed to the driver going to sleep. When all in the car are fatigued, including the driver, this is the worst time to continue driving with an unrestrained child.

Misuse of child restraints

Misuse can be dangerous, and examining crashes for evidence of misuse was a prime objective of the study. We found some cases of minor misuse, such as less-than-ideal adjustment of the child harness, that did not cause problems. However, there were sufficient cases of serious misuse to cause real concern.

In particular, all five cases of misuse of a Type B restraint - among which four were associated with injury or death - included failure to fasten the top tether. The top tether is an essential component of a complete restraint system because it stabilises the seat and prevents the excursion that contributes to injury. Without it, the restraint will simply not work as intended. Every effort should be made to educate and persuade those who use restraints that this is perhaps the single most important feature of the system. Parents who buy from uncaring department stores, who do not read instructions, who pass restraints among themselves or who buy second hand are all relatively unlikely to be aware of the importance of the top tether.

GENERAL OBSERVATIONS: THE FUTURE OF CHILD RESTRAINT

The general findings of this study are good news for parents and others who seek protection for their children in cars: child restraints are exceedingly effective in preventing injury, and adult belts also work very well in protecting children. The main causes of injury are intrusion into the occupant space and improper use of the restraints. The only injuries resulting from the forces of deceleration were bruising and abrasions as a result of webbing loads. Injuries resulted from invasion of the space of the properly restrained child by intrusion of the interior, collapsing seats, flying objects and flying glass. There was no relationship between ΔV and injury severity for children restrained in forward-facing seats, which emphasises that factors such as intrusion are more influential than impact speed.

These findings are entirely consistent with those in the United States of Agran (1984) and, more recently, of Kelleher-Walsh *et al* (1993).

The study reported here, earlier Australian studies, and recent studies of fatalities such as that of Rattenbury and Gloyns (1993) have confirmed the overwhelming importance of head injury in determining the outcome for a restrained child in a crash. While protection of the neck of the child is important, more important is the limitation of excursion of the head and upper torso. Where there is conflict between ways to bring about these aims, the protection of the head should take priority. It is our experience, based on this study, that to the extent that protection of the head requires firm anchorage of the seat and firm restraint of the upper torso of the child, this does not present an undue threat to the child's neck. In the absence of firm restraint of the upper torso, the resulting flexion of the torso will result in axial distraction loadings on the cervical spine that are at least as threatening to the spinal cord as flexion of the cervical spine on a firmly-held torso. When the neck is being stretched under axial load, even minor head contacts can result in fracture/dislocation of the cervical spine.

FIGURE 24 - Prototype Isofix seat, showing mounting points that lock into permanent fittings in the car

There are two implications for vehicle and child restraint design. One is that a design rule, such as the US Federal Motor Vehicle Safety Standard 213 for child restraints, that permits excursion of the head well into the space already occupied by vehicle structures in modern standard-sized cars requires review. A child's head that swings to the present (US) 32 inch limit will almost inevitably hit something. The other is that new restraint systems that include firm mountings and multipart harnesses, such as those envisaged by manufacturers working towards the Isofix principle, will provide good protection to the head and neck without presenting a new risk to the forward-facing normal child.

The Isofix concept will also help to minimise misuse. It was no surprise to find in our study that some of the worst injuries occurred as a result of blatant misuse in regard to installation either of the restraint or the child. We felt sorry for parents who, in many cases, had been given or bought second-hand child seats with no legible instructions, or who were faced by the task of installing a new restraint that challenges even the experienced. Anything that makes safe installation easier will improve the performance of the restraint system overall.

With some 40% of rear-seat passengers in Australian cars being children, moves by vehicle manufacturers to integrate dedicated child safety seats into the structures of cars are well overdue. Recent developments and movements into the world market by some European and American manufacturers are very encouraging. Integrated seats bypass the problems of installation and use that can lead to a hazard for restrained children. Integrated child restraints can take account of other developments such as air bags, seat belt tensioners, adjustable anchor points and so on. Further, by being incorporated with the vehicle at the design stage, the full benefit of the vehicle's crush and ride-down characteristics can be realised.

In this country, the requirements for after-market child restraints are a matter for Standards Australia while requirements specific to the vehicle (such as restraint mountings) are a matter for Australian Design Rules, administered by the Federal Office of Road Safety (FORS). In Europe and the United States regulations for integrated child seats are harmonised with existing performance-related vehicle standards such as the ECE R44 requirement and the US FMVSS 213. Particularly in regard to some specifics on componentry, the current Australian Standard for child restraints differs in several respects from these more broad-brush overseas standards. It would be a tragedy if overseas manufacturers felt constrained in providing cars for the Australian market by the threat that their equipment might not receive approval from all relevant authorities, and it is thus vital that Standards Australia, FORS, the vehicle manufacturers and all others concerned urgently solve any problems of compatibility and harmonisation of standards and requirements.

8 CONCLUSIONS

GENERAL

There are few safety devices that are as effective as child restraints. One of the main objectives of this present study was to determine whether there had arisen in recent years any substantial or common problems with child restraints. The indications are that this has not been the case. The vast majority of children in the study who were restrained in child restraints suffered only trivial or minor injury. Indeed, this study has confirmed that a child restraint is an exceedingly effective piece of safety equipment.

The study also confirmed that adult belts do not offer any special threat to children, and that children of any age for whom a dedicated child restraint is available must use an adult belt, preferably a three-point lap/sash belt in a rear seat.

CHILD RESTRAINTS

When children are injured in forward-facing Type B child restraints with harnesses and top tethers, injury is most likely to be a result of intrusion, contact with nearby parts of the vehicle's interior and other occupants, invasion of the child's space by collapsing seat backs, flying glass and other such mechanisms. Injury is unlikely to occur from the forces of deceleration alone.

The head remains the most important part of the body to be protected. The child is at risk if allowed to move out of its survival space, and restraint design should place a high priority on the minimisation of excursion of the upper body in order to prevent head contact.

The use of forward-facing restraints, even by small children in high-speed frontal collisions, does not appear to place the necks of children at especial risk from flexion injury. The study failed to disclose any neck injuries in the absence of direct head/neck contacts. Several children of around two and three years of age rode out extremely severe frontal crashes without neck injury. These were crashes with forces towards the limits of survival for any restrained human, and the children rode them out at least as well as - and generally better than - the adults in the same cars.

The only injuries caused by deceleration alone were bruising and abrasion from loads imparted from harness and seat-belt webbing, and some minor internal injuries.

Present data indicate that the main limitations of child restraints are analogous to those of adult seat belts, namely that in side impacts they provide not as good protection as in frontal impacts and that in severe crashes they still allow contact with injurious parts of the car interior. Improper installation and use remains a problem.

Many of these disadvantages can be at least partly overcome by incorporating child restraints into the car as part of the design and manufacturing process. The ISOFIX concept, which embodies a move towards international standardisation of rigid mountings for both forward and rearward-facing seats, is a step in the right direction. Integrated child restraints manufactured as part of the car can take account of other developments such as air bags, seat belt tensioners, adjustable anchor points and so on. Integration would also mean that the restraints would be developed and tested together with the rest of the motor vehicle.

ADULT BELTS USED BY CHILDREN

Lap/sash belts were shown to provide good protection for children, even in high-speed crashes. The main disadvantage of lap/sash belts is that at present they are only available for children sitting in outboard positions, where they are vulnerable to injury from intrusion and contact with the vehicle interior. Children (and adults) would be much safer if they could use lap/sash belts in centre seats, but at present in the vast majority of cars the only restraint available in centre seats is the inadequate lap-only belt.

Given the very high protective capacity of dedicated child restraints, parents should be
encouraged to use them until the children the child approaches the maximum approved mass, or is manifestly too big for the seat. At present, the indications from this study are that parents move children out of the seats and into adult belts too early.

UNRESTRAINED CHILDREN

Many children still ride unrestrained, or in adults' arms. Even in comparatively minor crashes, such children are at severe risk of injury or death. There were several cases in the study where fatigued children were being thus cradled in a car that was being driven by a driver who also may have gone to sleep.

MISUSE OF RESTRAINTS

The most dangerous form of misuse to be demonstrated by the study is the combination of a booster seat with a lap belt alone. The centre-seat lap belt is in itself an incomplete restraint, and its disadvantages - such as the threat of abdominal injury from belt loadings, and head and neck injuries resulting from excessive excursion - are magnified if the child is sitting on a booster seat as well.

VEHICLE DESIGN

Some private vehicles with the capacity to carry large numbers of people at a time - such as some four-wheel drive vehicles and multipassenger "people-carriers" - are not well adapted, or are difficult to adapt, to the safe carriage of children. When many children are carried in them, as is their intent, some of those children will be at more risk than in a conventional passenger car.

DATA SYSTEMS

There is a need to develop a routine accident surveillance system that identifies uninjured passengers, so that attention can be directed not only at problems resulting in injury but also at the upper limits of *successful* performance of child restraints. At present, such cases are not routinely recorded in any way.

In particular, there is a need for notification and investigation of crashes in country areas, which are usually at comparatively high speed. The effectiveness of restraints in low-speed collisions is beyond doubt. In is in protection in the more severe accidents that advances could lie. Monitoring of real-world accidents that do not result in injury is particularly necessary when new developments are introduced into the market, such as the recent move away from body bands and towards harnesses in infant capsules.

9 REFERENCES

ABS, *Motor Vehicle Census, Australia, 30 June 1993*, Ian Castles, Australian Statistician, Australian Bureau of Statistics Catalogue No. 9309.0, 1993.

Agran P.F. and Winn D.G., *Injuries Among 4 to 9 Year Old Restrained Motor Vehicle Occupants by Seat Location and Crash Impact Site*, in *Proceedings, 32nd Annual Conference, Association for the Advancement of Automotive Medicine*, Seattle, AAAM, 1988.

Agran P.F., and Winn D., *Traumatic Injuries Among Children using Lap Belts and Lap/shoulder Belts in Motor Vehicle Collisions*, in *Proceedings, 31st Annual Conference, American Association for Automotive Medicine*, New Orleans, AAAM, 1987.

Agran P.F., Dunkle D.E., and Winn D.G., *Restraint Usage Patterns of Children Less than Four Years of Age Evaluated in a Medical Setting After a Motor Vehicle Accident*, in *Proceedings, 28th Annual Conference, American Association for Automotive Medicine*, Denver, AAAM, 1984.

Agran P.F., Dunkle D.E., and Winn D.G., Injuries to a sample of seat belted children evaluated and treated in a hospital emergency room, *Journal of Trauma*, 27: 58-6, 1987.

Agran P.F., Winn D.G., and Castillo D.N., *On Lap Travel Still a Problem in Motor Vehicles*, in *Proceedings, 35th Annual Conference, Association for the Advancement of Automotive Medicine*, Toronto, AAAM, 1991.

Anderson P.A., Rivara F. P., Maier R.V., and Drake C., The epidemiology of seat belt associated injuries, *Journal of Trauma*, 31: 60-67, 1991.

Association for the Advancement of Automotive Medicine, *The Abbreviated Injury Scale: 1990 Revision*, Association for the Advancement of Automotive Medicine, Des Plaines Illinois, 1990.

Association for the Advancement of Automotive Medicine, *Injury Impairment Scale: 1994*, Association for the Advancement of Automotive Medicine, Des Plaines Illinois, 1994.

Baker S.P., O'Neill B., and Karph R.S., *The Injury Fact Book*, Lexington Books, Lexington, USA, 1984.

Baker, S. P., O'Neill, B., Haddon, W., and Long, W. B., A method for describing patients with multiple injuries and evaluating emergency care, *Journal of Trauma*, 14:187-196, 1974.

Bohlin N., *Statistical Analysis of 28,000 Accident Cases with Emphasis on Occupant Restraint Value*, in *Proceedings, 11th Stapp Car Crash Conference*, Society of Automotive Engineers, 1968.

Booth M.V., *A Review of Compatibility Problems Between Vehicles and Child Restraints*, in *Proceedings, Road Traffic Safety Seminar,* Road Traffic Safety Research Council, Wellington, New Zealand, 1988.

Burdi A.R., Huelke D.F., Snyder R.G. and Lowrey G.H., Infants and children in the adult world of automobile safety design: paediatric and anatomical considerations for design of child restraints, *Biomechanics*, 2: 267-280, 1969.

Campbell B.J., *The Effectiveness of Rear Seat Lap Belts in Crash Injury Reduction*, University of North Carolina, Highway Safety Research Centre, Chapel Hill, NC, 1986.

Carlsson G., Norin H., and Ysander L., Rearward-facing child seat - the safest car restraint for children? *Accident Analysis and Prevention*, 23 (2/3): 175-182, 1991.

Carlsson G., Norin H., and Ysander L., Rearward-facing child seat - the safest car restraint for children? *Accident Analysis and Prevention*, 23 (2/3): 175-182, 1991.

Conry B.G., and Hall C.M., Cervical spine fracture and rear car seat restraints, *Archives of Diseases in Children*, 62: 12-67, 1987.

Corben C.W., and Herbert D.C., *Children Wearing Approved Restraints and Adult's Belts in Crashes*, Traffic Accident Research Unit, Report 1/81, Department of Motor Transport, NSW, 1981.

Corner J. P., Whitney C. W., O'Rourke N., and Morgan D.E., *Motorcycle and Bicycle Protective Helmets: Requirements Resulting from a Post Crash Study and Experimental Research*, School of Civil Engineering, Queensland Institute of Technology, for the Federal Office of Road Safety, Report No. CR 55, Department of Transport and Communications, Canberra.

Cynecki M.J. and Goryl M.E., *The Incidence and Factors Associated with Child Safety Seat Misuse*, DOT HS 806 676, Goodell-Grivas, Southfield, MI, for the

Department of Transportation, Washington, DC, 1984.

Czernakowski W. and Muller M., *Misuse Mode and Effects Analysis (MMEA): An Approach to Predict and Quantify Misuse of Child Restraint Systems*, in *Proceedings, 35th Annual Conference, Association for the Advancement of Automotive Medicine*, Toronto, AAAM, 1991.

Day, T.D. and Hargens, R.L, *Further Validation of EDCRASH Using the RICSAC Staged Collisions*, SAE paper 890740, Society of Automotive Engineers, Warrendale PA, 1989.

Dejeammes M., Tarriere C., Thomas C., and Kallieris D., *Exploration of Biomechanical Data Towards a Better Evaluation of Tolerance for Children Involved in Automotiuve Accidents*, SAE 840 530, in *Advances in Belt Restraint Systems*, Society of Automotive Engineers, 427-440, 1984.

Department of Transportation, *Effectiveness of Safety Belt Use Laws, A Multinational Examination*, DOT Report HS807018, Washington, DC, 1986.

Engineering Dynamics Corporation, *Engineering Dynamics Vehicle Analysis Package (EDVAP)*, Fourth Edition, Engineering Dynamics Corporation, Oregon, 1989.

Evans L., *Traffic Safety and the Driver*, Van Nostrand Reinhold, New York, 1991.

Evans L., The effectiveness of safety belts in preventing fatalities, *Accident Analysis and Prevention*, 18: 229-241, 1986.

Evans L., Risk of fatality from physical trauma versus sex and age, *Journal of Trauma*, 28: 368-378, 1988.

Fildes B.N., Lane J.C., Lenard J., and Vulcan A.P., *Passenger Cars and Occupant Injury*, Monash University Accident Research Centre, for the Federal Office of Road Safety, Report CR 95 March 1991, Department of Transport and Communications, Canberra, 1991.

Fuchs S., et al, Cervical spine fractures sustained by young children in forward-facing car seats, *Paediatrics*, 84(2), 1989.

Henderson J.M., Herbert D.C., Vazey B.A. and Stott J.D., *Performance of Child Restraints in Crashes and in Laboratory Tests*, in *Proceedings, Seat Belt Seminar*, Melbourne 1976, Commonwealth Department of Transport, Canberra, 1976.

Herbert D.C., Vazey B.A., Wyllie J.M., Leitis V., Stott J.D., and Vaughan R.G., *Crash Protection for the Sub-Teen Child*, Traffic Accident Research Unit Report 4/74, Department of Motor Transport, NSW, 1974.

Herbert D.C. and Cutting D., *Crash Protection for Children After Their Third Birthday*, Traffic Accident Research Unit Report 2/78, Department of Motor Transport, NSW, 1978.

Herbert D.C., Vazey B.A. and Stott J.D., *Car Crash Protection of Children, Principles and Practice*, in *Proceedings 7th Annual Conference, Australian Road Research Board*, 197, 1974.

Huelke D.F., *The Effectiveness of Belt Systems in Frontal and Rollover Crashes*, in *Proceedings, Sixth International Conference of the International Association for Accident and Traffic Medicine,* Melbourne, 1977.

Huelke D.F., Mackay G.M., Morris A, and Bradford M., *Car Crashes and Non-Head Impact Cervical Spine Injuries in Infants and Children*, SAE Technical Paper Series 920562, SAE International Congress, Detroit, Society of Automotive Engineers, Warrendale PA, 1992.

Janssen E.G. Huijskens C.G., Verschut R., and Twisk D., *Cervical Spine Loads Induced in Restrained Child Dummies II*, SAE paper 933102, in *Child Occupant Protection*, SP-986, Society of Automotive Engineers, Warrendale PA, 1993.

Kahane C.J., *An Evaluation of Child Passenger Safety: The Effectiveness and Benefits of Safety Seats*, DOT Report HS 806890, National Highway Traffic Safety Administration, Department of Transportation, Washington, DC, 1986.

Kamren, B., v Koch M., Kullgren A., Lie A, Tingvall C., Larsson S. and Turbell T., *The Protective Effects of Rearward Facing CRS: An Overview of Possibilities and Problems Associated with Child Restraints for Children Aged 0-3 Years*, in *Child Occupant Protection*, SP-986, Society of Automotive Engineers, Warrendale PA, 1993.

Kelleher-Walsh B., Walsh M.J., States J.D. and Duffy L.C., *Trauma to Children in Forward-Facing Car Seats*, SAE paper 933095, in *Child Occupant Protection*, SAE SP-986, Society of Automotive Engineers, Warrendale PA, 1993.

Lane J.C., *The Child in the Centre Seat*, Monash University Accident Research Centre, for the Federal Office of Road Safety, Report CR 107, Department of Transport and Communications, Canberra, 1992.

Langwieder K, and Hummel T, *Neck Injuries to Restrained Children,* in *Proceedings, Annual Conference of the International Research Committee for the Biokinetics of Impact: Workshop on the Future of Child Restraints,* 1989.

Lowne R., Gloyns P., and Roy P., *Fatal Injuries to Restrained Children aged 0-4 years in Great Britain, 1972*, in *11th International Technical Conference on*

Experimental Safety Vehicles, 1987, National Highway Traffic Safety Administration, Department of Transportation, Washington, DC, 1988.

Lundell B., *Rear Seat Safety*, Euro Traffic '91, European Traffic Congress, Volvo Car Corporation, Gothenberg, Sweden, 1991.

Lundell B., Carlsson G., Nilsson P., Persson M. and Rygaard C., *Improving Rear Seat Safety, A Continuing Process*, in *Proceedings, 13th International Conference on Experimental Safety Vehicles*, Department of Transportation, Washington, DC, 1991.

Lundell B., Claesson P., and Turbell T., *Experience from Four Years of Activity in the ISO Working Group on Child Restraint Syustems*, SAE paper 933083, in *Child Occupant Protection*, SP-986, Society of Automotive Engineers, Warrendale PA, 1993.

Mattern R. Barz J., Schulz F., Kallieris D., and Schmidt G., *Problems Arising When Using Injury Scales in the Biomechanical Investigation with Special Consideration of the Age Influence*, in *Proceedings Fourth International IRCOBI Conference on the Biomechanics of Trauma*, Goteborg, IRCOBI, 1979.

Melvin J.W., Weber K. and Lux P., *Performance of Child Restraints in Serious Crashes*, in *Proceedings, 24th Annual Conference, American Association for Automotive Medicine*, Rochester, AAAM, 1980.

Newman K.D., Bowman L.M., Eichelberger M.R., Gotschall C.S., Taylor G.A., Johnson D.L., and Thomas M., The lap belt complex: intestinal and lumbar spine injury in children, *Journal of Trauma*, 30: 1133-1138, 1990.

Norin H., Carlsson G. and Korner J., *Seat Belt Usage in Sweden and its Injury Reducing Effect*, in *Advances in Belt Restraint Systems Design Performance and Usage*, P-141, Society of Automotive Engineers, Warrendale PA, 1984.

Partyka S.C., *Belt Effectiveness in Fatal Accidents*, in *Papers on Adult Seat Belt Effectiveness and Use*, DOT Report HS 807285, National Highway Traffic Safety Administration, Department of Transportation, Washington, DC, 1988.

Petrucelli E., Child Restraint Misuse in the USA, Implications for Crash Protection, *IRCOBI Workshop on Future in Child Restraints*, Association for the Advancement of Automotive Medicine, 1989.

Planath I., *Synthesis of data towards neck protection criteria for children*, 1992 IRCOBI Conference, Verona, 1992.

Rattenbury S.J. and Gloyns P.F., *A Population Study of UK Car Accidents in Which Restrained Children Were Killed*, in *Child Occupant Protection*, SP-986, Society of

Automotive Engineers, Warrendale PA, 1993.

Road Safety Bureau, *Road Traffic Accidents in New South Wales, Statistical Statement: 1992*, Roads and Traffic Authority, 1993.

Road Safety Bureau, *Child Restraint and Seat Belt Usage Survey, November 1993*, Roads and Traffic Authority, 1994.

Schmidt G., *The Age as a Factor Influencing Soft Tissue Injuries*, in *Proceedings Fourth International IRCOBI Conference on Biomechanics of Trauma*, Goteborg, IRCOBI, 1979.

Smith M.A., Jalaludin B., Leeder S.R. and Smith W.T, Isn't one institutional ethics committee's approval enough? (letter), *Medical Journal of Australia*, 160: 662, 1994.

Snyder R.G., and O'Neill B., Are 1974/1974 automotive belt systems hazardous to children, *American Journal of Diseases of Children*, 129: 946., 1975.

Society of Automotive Engineers, *Anthropometry of Infants, Children and Youths to age 18 for Product Safety Design*, SAE Paper SP 450, Society of Automotive Engineers, 1980.

Stalnaker R.L., *Spinal Cord Injuries to Children in Real World Accidents*, SAE paper 933100, in *Child Occupant Protection*, SP-986, Society of Automotive Engineers, Warrendale PA, 1993.

Standards Australia, *Child Restraint Systems For Use In Motor Vehicles: AS 1754-1991/NZS 5411:1991*, Standards Australia and Standards Association of New Zealand, North Sydney, NSW, Australia, and Wellington NZ, 1991.

Sturtz G., *Biomechanical Data of Children*, SAE 801 313, in *Proceedings 24th Stapp Car Crash Conference*, Troy, Michigan, Society of Automotive Engineers, 1980.

Tingvall C., Children in Cars, Some Aspects of the Safety of Children as Car Passengers in Road Traffic Accidents, *Acta Paediatr. Scand., Suppl.*, 339: 1-35, 1987.

Trossielle X. and Tarriere C., *Neck Injury Criteria for Children from Real Crash Reconstructions*, SAE paper 933103, in *Child Occupant Protection*, SAE SP-986, Society of Automotive Engineers, Warrendale PA, 1993.

Turbell T., Lowne R., Lundell B. and Tingvall C., *ISOFIX - A New Concept of Installing Child Restraints in Cars*, in *Child Occupant Protection*, SP-986, Society of Automotive Engineers, Warrendale PA, 1993.

Traffic Authority of NSW, *A Guide to the Correct Installation and Use of Seat Belts and Child Restraints*, for the Federal Office of Road Safety, Traffic Authority of NSW, 1988.

Tumbas, N.S., undated, *National Accident Sampling System Field Techniques*, Institute for Research in Public Safety, School of Environmental and Public Affairs, Indiana University, for the National Highway Traffic Safety Administration, Department of Transportation, Washington DC.

Vazey, B.A., Herbert, D.C. and Leitis V., *Crash Protection for Babies*, Traffic Accident Research Unit Report 2/74, NSW Department of Motor Transport, 1974.

Vazey B., *Child Restraint Field Study*, Traffic Accident Research Unit Report 7/77, NSW Department of Motor Transport, 1977.

Weber K. and Melvin J.W., *Injury Potential with Misused Child Restraining Systems*, SAE 831604, in *Proceedings, Stapp Car Crash Conference*, San Diego, Society of Automotive Engineers, Warrendale, PA, 1983.

Weber K., *Child Restraint and Airbag Interaction: Problems and Progress*, SAE paper 933094, in *Child Occupant Protection*, SP-986, Society of Automotive Engineers, Warrendale PA, 1993.

Weber K., Dalmotas D. and Hendrick B., *Investigation of Dummy Response and Restraint Configuration Factors Associated with Upper Spinal Cord Injury in a Forward-Facing Child Restraint*, SAE paper 933101, in *Child Occupant Protection*, SP-986, Society of Automotive Engineers, Warrendale PA, 1993.

Wesson D.E., Williams J.I., Spence L.J. Filler R.M. and Armstrong P.F., *Use of the Injury Severity Score (ISS) in a Paediatric Population*, in *Proceedings, 30th Annual Conference, American Association for Automotive Medicine*, Montreal, AAAM, 1986.

APPENDIX

INFORMATION LETTER AND CONSENT FORM

Under the letterhead of the Child Accident Prevention Foundation of Australia (NSW Division) an information letter was sent or taken personally to parents or guardians whose children were potentially in the study. The following is an example of such a letter (each letter differed in detail because of varying requirements of the different Institutional Ethics Committees).

CAPFA CHILD OCCUPANT INJURY STUDY

Dear

You are invited to participate in a study of how children are injured when they have been riding in cars involved in road accidents. The study is aimed at improving the safety of our vehicles, seat belts and child safety seats. You were selected as a possible participant because your child was injured recently in a road accident.

If you decide to participate, we would like to talk to you about the crash and find out about your child's injuries. This will necessarily involve us looking at your child's medical record file at the hospital or held by the doctor.

For this research we also need to examine vehicles involved in road accidents to work out exactly happened in real crashes. We also examine any safety devices, such as seat belts, child seats or infant carriers that might have been used. We can then relate any damage to the injuries that children have suffered.

So, we would like your permission to inspect the vehicle and to make a number of photographs and measurements of the damaged areas. We would also like to inspect any special child safety equipment that might have been removed. We assure you that our work will not interfere with your vehicle in any way, or delay the repair of your car.

Any information about you or your child that is obtained in connection with this study will remain confidential and will be disclosed only with your written permission. It is not being gathered for legal reasons, although we cannot guarantee that, pending destruction of the records, it will not be used in a court. The results of the study may be published or disclosed to other people in a way that will not identify you or your child. We hope in this way to prevent children being injured in the future.

Whether you take part in this study or not, it will make no difference to the medical treatment your child will receive. If you decide to take part in the study, you can still pull out at any time, and this will not make any difference to your child's treatment either.

On the other side of this letter there is a consent form for you to sign. This authorises us to obtain details about your injuries and inspect your vehicle. Please sign and date this form if you are willing to participate in this important study. You will be given a copy to keep. If you have any questions at any time, I will be happy to answer them. The hospital requires that all participants in this study be informed that if they have any complaint about the way the research is conducted, they may take their complaint to me or, if an independent person is preferred, to the Quality Assurance Officer, HAREC, Room 315 Nurses Home, Royal Newcastle Hospital, Pacific Street, Newcastle 2300 (tel 266 432).

Yours sincerely,

(Dr) Michael Henderson
Chief Investigator, Child Occupant Injury Study

****

CERTIFICATION BY INVESTIGATOR AND PARENT/GUARDIAN

I hereby certify that I have disclosed all the facts relating to the CAPFA child occupant injury study in terms readily understood by the child's parent or guardian.

Date. . . . . .Signature of Investigator. . . . .

CONSENT BY PARENT OR GUARDIAN

I hereby certify that I have read and understood all the information provided and agree to participate in the research proposal described on the other side of this page. I have been informed that approval has been given by the hospital's

Research Ethics Committee. I understand that my child can withdraw from the study at any time without affecting medical care. I can refuse on my child's behalf.

Date. . . . . .Signature of Parent/Guardian . . . .

Relationship to child . . . .

Signature of witness

Nature of witness

****

REVOCATION OF CONSENT BY PARENT/GUARDIAN

I hereby wish to withdraw my consent to participate in the research proposal described above and understand that such withdrawal will not jeopardise any treatment or my relationship with the hospital or my child's medical attendants.

Date. . . . . .Signature of Parent/Guardian . . . .

The section for revocation of consent should be sent to Dr Michael Henderson, Child Accident Prevention Foundation of Australia, Level 6, Wingello House, 1-12 Angel Place, Sydney NSW 2000.