SOME OBSERVATIONS ON THE MODELLING OF CHILDREN IN CAR COLLISIONS BASED ON FIELD ACCIDENT INVESTIGATIONS

by

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ABSTRACT

Some of the risks and causes of injury to children associated with being unrestrained in car collisions are outlined, based on a sample of high energy crashes. Data from a questionnaire survey of a separate sample of 663 children who were wearing some type of restraint system in collisions is presented. For unrestrained children the results from these studies show that head injuries are very important, and partial ejection is a frequent mechanism of injury. For restrained children head injuries are the most common type of injury and intrusion and lateral loading are dominant causal factors. There is no evidence of severe neck injuries for restrained children nor any suggestion that deceleration forces without specific contacts are generating major injuries. Intrusion, seat movement and seat damage are the main factors which prejudice the safe ride-down envelope. Some consequences of these data are reviewed in relation to the problems of the dynamic modelling of young car occupants.

INTRODUCTION

The data in this paper comes partly from the files of the Accident Research Unit at Birmingham University and partly from answers to questionnaires completed by people involved in collisions in which a child restraint had been used. The purpose of this paper is to examine the real-world accident conditions in which child restraints are worn, so that the limiting conditions governing their effectiveness can be evaluated. By such studies we hope that a better insight into the actual limits of protection can be provided so that the dynamic modelling of child occupants can be made more realistic and levels of protection increased.

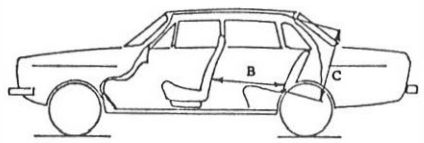
Several analyses of different data sets are presented. Firstly, a sample of unrestrained children is examined to demonstrate the frequency and anatomical distribution of their injuries, related to certain collision characteristics. Secondly, an analysis is made of the answers to questionnaires returned by people involved in collisions in which a child was using a restraint system. To supplement that accident data, 16 additional cases taken from the ARU files in which children were using their restraints are reviewed. Thirdly, the frequency and position of intrusion into the passenger compartment is discussed based on a separate sample of fatal collisions, because intrusion appears as an important limiting feature in the protection of children. Finally, the particular feature of the performance of folding rear seat backs in impacts is reviewed because in estate cars and hatchbacks the release of the rear seat back appears to be an event which could well reduce the effectiveness of some child restraint systems.

DEFINITION OF VARIABLES

The two basic independent variables used in many analyses of accident data relate to injury severity and collision severity. In this study the 1976 revision of the A.I.S. is used to rank the injuries (A.A.A.M. 1976); and collision severity is assessed using the Equivalent Test Speed (ETS) concept (Mackay and Ashton 1973). In addition a safe ride-down envelope (SRDE) for a child in the rear of a car has been defined. This envelope defines the space in which a child may move without making a contact with the undeformed car structure.

For children seated in the centre rear seating position, the dimensions of the SRDE were investigated for 74 types of cars representing the majority of registrations in the U.K. in 1974. The SRDE approximated to a parallelepiped of leading dimensions B, C and I, which are defined in Fig. 1. The variation

FIGURE 1 DEFINITION OF DIMENSIONS B, C and I



Dimension I = interior width of rear compartment at head level

of dimension B, the distance between the rear of the front seat and the rear seat back, represents the safe limit of forward movement for a restrained child in a frontal impact. 96% of the vehicles had dimension B (when the seat was in its most rearward position) ⩾ 508mm, and C>826mm and I⩾1080mm. Some data supplied by TNO for 38 types of car in the Netherlands showed that 97% had a value of B⩾560mm. The angle of the parallelogram is that of the angle of the front seat back.

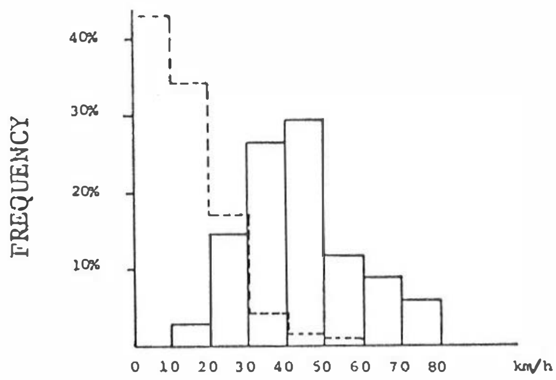
SERIOUS AND FATALLY INJURED UNRESTRAINED CHILDREN IN HIGH ENERGY COLLISIONS

This sample consisted of 93 children in 61 cars. One criterion governing the selection of cases to be included in this sample was that at least one child in the car had to be seriously or fatally injured. The general method of investigation has been described elsewhere (Gloyns 1974).

Fig. 2 shows that 26.5% of the accidents in the sample were above an ETS of 50km/h and 2.9% below 20 km/h; this is to be compared with 2% and 77% respectively reported by Mackay and Ashton (ibid) for a typical U.K. ETS distribution, thus showing that this sample is at the high energy end of the accident spectrum. Table 1 shows the direction of impact force. This distribution is not significantly different from a typical U.K. distribution reported by Mackay and Ashton (ibid).

FIGURE 2 ETS DISTRIBUTION

Frontal Impacts



EQUIVALENT TEST SPEED (ETS)

——— Representative Sample Mackay & Ashton (1973).

TABLE 1 DISTRIBUTION OF DIRECTION OF IMPACT FORCE (CLOCK CODE) (N = 61)

Direction	12	1	2	3	4	5	Roll	5.4%
%	53.8	4.3	12.9	4.3	1.1	0		
Direction	6	7	8	9	10	11	Complex	1.1%
%	0	0	1.1	5.4	0	8.6		

The seating positions of the children shown in Table 2 indicates that 30.1% were in the front passenger seats and 58.1% in the rear seats, with 11.8% in an unknown position. This is to be compared with the distribution reported by Lowne (1974) where 0 - 3 year olds the distribution was 37%, 63% and 4 - 12 year olds 23%, 77% in the front and rear respectively. Of the 93 children injured, 61 (65.6%) were seiously injured and 30 (32.3%) were fatally injured. 2 children (2.2%) had injuries which were suspected to be serious but were classified as unknown.

TABLE 2 SEATING POSITION (N = 93)

Position	%	
Front Passenger Seat	22.6	30.1%
On Lap of Front Seat Passenger	7.5	
Right Rear Seat	11.8	58.1%
Centre Rear Seat	4.3	
Left Rear Seat	14.0	
In rear, actual seat position unknown	28.0	
Position in vehicle not known	11.8	

TABLE 3 INJURY DISTRIBUTION FOR UNRESTRAINED CHILDREN

Sample Size 93 Children

Body Location	Frequency - AIS 01	02	03	04	05	06	Total
Head	10	28	8	1	17	8	72
Face	25	14	4	2	0	0	46
Neck	0	1	2	0	1	1	5
Chest/Shoulder	5	3	14	0	3	0	25
Abdomen	2	0	1	5	6	0	14
Arm	15	9	2	2	0	0	28
Leg	14	13	3	1	0	0	31
Back	3	0	1	0	1	0	5
Shock Only	1	0	0	0	0	0	1
							227

TABLE 4 SUMMARY OF LOCATION OF INJURIES GROUPED BY HEAD, TORSO AND EXTREMITIES

N = 227

Head Zone (Head/Face/Neck)	Torso (Chest/Shoulder/ Abdomen/Back)	Extremities (Arm/Leg)	Shock Only
54.2%	19.4%	26.0%	0.4%

Table 3 shows the injury distribution at a given body location by severity, whilst Table 4 shows the distribution of the injuries by grouped body zone i.e. head zone (head, face and neck), torso and extermities (arms and legs). Table 5 shows the injury data analysed by the location of the injury of highest severity. Thus the overall distribution of location of injuries shows that the head zone is the most common location (54.2%) comprising 31.8% head, 20.3% face and 2.2% neck. The next most common zone being the extremities (26%) comprising 13.6% legs and 12.4% arms.

However, perhaps the most important division of all is that between non-life threatening (AIS 1 - 3) and life threatening (AIS 4 - 6), shown in Table 6. The sequential order for non-life threatening injuries was head 20.3%, face 18.9% and legs 13.2%; whereas for life threatening injuries the order was head 11.5% abdomen 4.8%, followed by face and chest/shoulders 1.3%.

Thus it will be seen that injuries to the neck represent only 2.2% of the total, the neck location being ranked seventh out of the nine body locations. Further it will be noted that 50 of the 93 children had their most severe injury at the head and a further 12 had an injury to the head and another location of equal maximum severity. This means that 76.5% of the children had injuries to the head which were either of the maximum severity or equal maximum severity with another body location. Thus it is concluded that the head is the location with the highest frequency of injuries, both non-life threatening and life threatening.

TABLE 5 DISTRIBUTION OF LOCATION OF INJURY BY HIGHEST AIS

Location	No. of times injury cited as highest AIS for a single body location	No. of times injury cited as highest AIS at more than one location	
Head	50	12	62
Face	2	5	7
Neck	2	0	2
Chest/Shoulder	2	3	5
Abdomen	2	3	5
Arm	4	5	9
Leg	6	1	7
Back	0	0	0

Total number of children where location of injury is known = 81
" " " " " " " " unknown = 12

TABLE 6 DISTRIBUTION OF AIS 1 - 3 AND 4 - 6 INJURIES GROUPED BY LOCATION

Total Number of Injuries = 227

% Injuries at Given Location

Location	AIS 1-3	AIS 4-6	Total
Head	20.3	11.5	31.8
Face	18.9	1.3	20.2
Neck	1.3	0.9	2.2
Chest/Shoulder	9.7	1.3	11.0
Abdomen	1.3	4.8	6.1
Arm	11.5	0.9	12.4
Leg	13.2	0.4	13.6
Back	1.8	0.4	2.2
Shock Only	0.4	0	0.4
	78.4%	21.6%	100%

Table 7 shows the frequency of complete or partial ejection amongst seriously and fatally injured children. It may be that ejection is associated with relatively high energy accidents but these data suggest that ejection either partial or complete, may be an important injury - producing mechanism for unrestrained children.

TABLE 7 FREQUENCY OF COMPLETE OR PARTIAL EJECTION AMONGST SERIOUSLY AND FATALLY INJURED UNRESTRAINED CHILDREN

	Seriously Injured	Fatally Injured
Not ejected	56	25
Ejected (full or partial)	5	5
	61	30

DATA FROM THE QUESTIONNAIRE SURVEY

The Transport and Road Research Laboratory in conjunction with K.L. Automotive Limited have developed a questionnaire which asks parents who purchase child restraints to return the form completed if they are involved in a collision (Lowne 1974). This procedure has the advantage of providing relatively large numbers of cases but the detail and accuracy of the information is necessarily not as good as that coming from specialised investigations. These data include both restrained and unrestrained children, the latter coming from a car in which a child was restrained. The cases are classified as follows:-

Restrained groups -	12	children in restrained carrycots
	571	children in child seats
	80	children in child harnesses
	663	
Unrestrained groups -	23	children in unrestrained carrycots
	10	children on lap of front seat passenger
	66	children unrestrained.
	99	

These cases exhibited accident parameters indicating that the majority were relatively low speed collisions.

The seating distribution, Table 8, shows that a high percentage of the responses were such that the seat position had to be classified as unknown, due to an ambiguity on the questionniare form, but it was suspected that the overall majority of these children were in fact sitting in the rear. In order to investigate this hypothesis, observations were made of the positions in which 390 child seats and harnesses were fitted in vehicles. This was used as a control sample. These results showed that less than 0.5% of the vehicles had restraints which complied with BS. 3254 - 1960 fitted on the front passenger seat

TABLE 8 SEAT POSITION OF CHILDREN BY RESTRAINT

	% in Seat Position (Questionnaire)			Control Sample % Fitted by Restraint			
	Restrained Carrycot	Child Seat	Harness	Overall	Child Seat	Harness	Impact Shield
Front Passenger Seat	0	0.2	0	0.49	0.74	0	0
Right Rear Seat	8.3	1.2	1.3	29.27	24.16	39.17	0
Centre Rear Seat	0	1.2	1.3	23.90	28.25	15.83	0
Left Rear Seat	0	3.0	3.8	46.34	46.84	45.0	100
Somewhere in Rear	58.3	24.5	37.5	-	-	-	-
Position Unknown	33.3	69.9	57.5	-	-	-	-
Total N =	12	571	80	390	269	120	1

Thus it is reasonable to conclude that the majority of the children who were restrained either in seats or harnesses and who were classified as 'position unknown' were in fact in the rear seating positions.

The overall child age and mass distributions are shown in Table 9 and Figs. 3 and 4.

TABLE 9 SUMMARY OF AGE AND MASS STATISTICS FOR RESTRAINED CHILDREN

Age - Months Mass - kg

	Restrained Carrycot		Child Seat		Harness	
	Age	Mass	Age	Mass	Age	Mass
Mean	3.7	6.6	22.2	12.0	58.2	18.4
Std. Dev.	2.74	1.87	11.93	2.78	24.01	4.91
Range	1-9	3.6-8.2	5--84	5.5-25.5	5-121	6.4-31.8
Range implied by BS.3254	0-9	0-9	9-57	9-18	57-132	18-36

FIGURE 3 CUMULATIVE FREQUENCY - AGE - CHILDREN IN RESTRAINED CARRY COTS, CHILD SEATS AND HARNESSES

Age range implied in BS.3254 - 1960 for children in:-

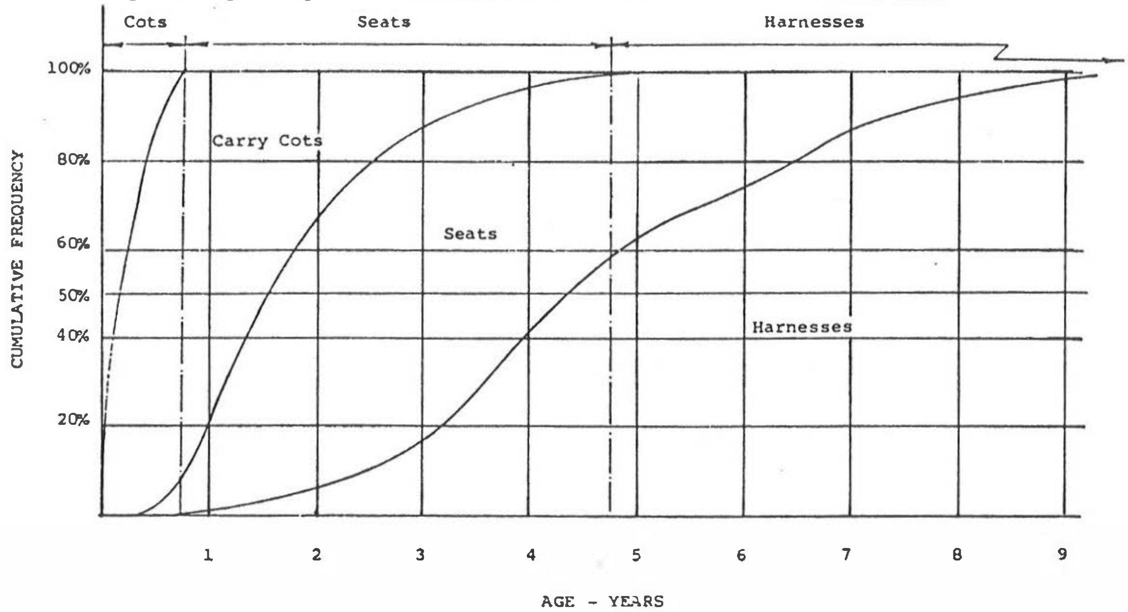
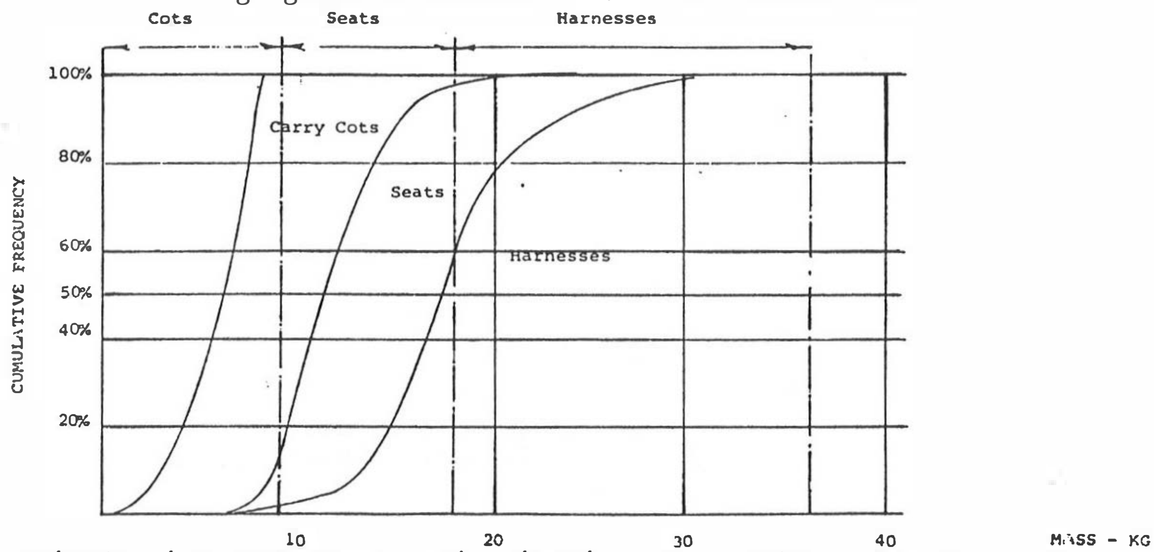


FIGURE 4 CUMULATIVE FREQUENCY - MASS - CHILDREN IN RESTRAINED CARRY COTS, CHILD SEATS AND HARNESSES

Mass range given in BS.3254 - 1960 for children in:-



Of particular interest are the distributions for children in seats and harnesses when compared with the appropriate ranges implied in BS.3254 - 1960. These indicate that although the majority of the children in seats were within the age/mass range implied by the standard, over 50% of the children in harnesses were younger than the minimum age (57 months) which is implied in the standard and hence of lower mass. The mean age of children in seats being 22 months compared with the age range implied by the standard of 9 - 57 months, whilst the mean age for the children in harnesses was 58 months compared with the range implied by the standard of 57 - 132 months.

Consequently, the mass range for the children in harnesses was 6.4 - 31.8 kg compared with the range in the standard of 18 - 36 kg. Hence for modelling purposes the field study indicates that the mass selected for children in harnesses should be lower than that given in the standard.

Injuries. Table 10 shows a summary of the location of injuries and Table 11 shows these locations grouped. For both unrestrained and restrained children the highest proportion of injuries occurred to the head zone, these being 63.0% and 52.8% respectively. The head zone was followed sequentially by the torso (14.8%) and the extermities (13.9%) for the restrained group, whereas this order was reversed for the unrestrained group being extremities (19.6%) and torso (8.7%) The distribution by severity was estimated on the AIS scale as shown in Table 12. It will be noted that 88.8% of the injuries to restrained children were classified as AIS 1.

TABLE 10 SUMMARY OF LOCATION OF INJURIES

Restrained Children KL Sample

	Restrained Carry Cot	Seat	Harness	Unrestrained carry cot	On Lap of Passenger	Unrestrained
Head	0	18	4	4	3	14
Face	1	22	4	1	3	4
Neck	0	7	1	0	0	0
Chest/ Shoulder	0	9	4	0	0	4
Abdomen	0	2	1	0	0	0
Arm	0	6	0	0	0	3
Leg	0	5	4	0	0	6
Back	0	0	0	0	0	0
Area Unknown	0	9	3	0	0	3
Shock Only	0	4	4	1	0	0
Total	1	82	25	6	6	34

Total Injuries 154 94 Restrained children
39 Unrestrained children

TABLE 11 SUMMARY OF LOCATION OF INJURIES GROUPED BY HEAD, TORSO AND EXTREMITIES, AND RESTRAINT USE.

	Head/Face/ Neck		Shoulder/Chest Abdomen/Back		Arm/Leg		Area Unknown		Shock Only	
	N	%	N	%	N	%	N	%	N	%
Restrained Children	57	52.8	16	14.8	15	13.9	12	11.1	8	7.4
Unrestrained Children	29	63.0	4	8.7	9	19.6	3	6.5	1	2.2

Total Injuries 154

TABLE 12 % OF INJURIES IN GIVEN ZONE BY SEVERITY FOR CHILDREN RESTRAINED IN SEATS AND HARNESSES

	AIS						
Seat	01	02	03	04	05	06	Total
Head/Face/Neck	51.2	4.9	1.2	-	-	-	57.3
Chest/Shoulder/ Abdomen/Back	12.2	1.2	-	-	-	-	13.4
Arms/Legs	9.8	3.7	-	-	-	-	13.5
Area Unknown	10.9	-	-	-	-	-	10.9
Shock Only	4.9	-	-	-	-	-	4.9
N = 82	89.0	9.8	1.2	-	-	-	100%

	AIS						
Harness	01	02	03	04	05	06	Total
Head/Face/Neck	28.0	8.0	-	-	-	-	36.0
Chest/Shoulder/ Abdomen/Back	20.0	4.0	-	-	-	-	24.0
Arms/Legs	12.0	-	-	-	-	-	12.0
Area Unknown	12.0	-	-	-	-	-	12.0
Shock Only	16.0	-	-	-	-	-	16.0
N = 25	88.0	12.0					100%

Of particular interest is the distribution of injury by body location for the injured children in seats and harnesses. A theoretical disadvantage of forward facing restraints in frontal impacts is that the head may apply loads leading to neck injury during the time that the child's torso is being decelerated by the restraint. For children with injuries of AIS 1, the number of neck injuries was 7 (9.5%) of the total of 73 for the children in seats, and 1 (4.3%) of the total of 22 for the children in harnesses. However, of the 7, 3 were bruises attributed to straps, 3 were reported as stiff necks, and 1 was unknown but not serious. There were no neck injuries estimated of severity greater than AIS 1 in these samples. For the restrained group, neck injury occurred with the same order of frequency as mouth lacerations and bruises to the torso. There was 1 AIS 3 head injury to a child restrained in a seat, but this was reported as a head contact due to intrusion of the roof structure.

Injury Agents. A summary of the injury agents for minor injuries (AIS 1) is given in Table 13. For children in seats and harnesses, the straps of the safety system were the most commonly quoted agent at 23.3% and 30.4% respectively. These were followed in sequential order by lacerations due to the child's own teeth

6.8% and vehicle internal components 4.1% for children in seats, whilst the order was reversed for children in harnesses being 8.7% and 13.1% respectively. Broken glass was reported as an injury agent in approximately 4% of the seat and harness cases.

TABLE 13 SUMMARY OF INJURY AGENTS

INJURY AGENTS FOR INJURIES ESTIMATED AS AIS 1 - %

Agent	Restrained Carry Cot	Seat	Harness	Unrestrained Carry Cot	On Lap of Passenger	Unrestrained
Teeth of child	0	6.8	8.7	0	0	0
Straps of Safety System	0	23.3	30.4	0	0	0
Vehicle Internal Components	0	4.1	13.1	16.7	50.0	17.2
Glass	0	4.1	4.3	16.7	0	17.2
Intrusion of Vehicle Structure	0	2.7	0	0	0	0
Occupant	0	1.4	0	0	0	0
Other or Unknown	100	57.6	43.6	66.6	50.0	65.5
	100%	100%	100%	100%	100%	100%

The observations based on these questionnaire data are in agreement with the general experience of restrained children in the ARU cases. Table 14 summarises the main features of the 16 cases which are from that source.

INTRUSION

Several authors, Henderson and Wyllie (1973), Mackay et al (1975), and Griffiths et al (1976) have identified intrusion as a factor which prejudices the performance of adult seat belts. In order to investigate the effects of intrusion, a sample of fatal accidents was analysed from the files of the ARU in order to compare the frequency of intrusion in each of the five seating positions found in the majority of U.K. vehicles. This sample consisted of accident cases representing 229 cars drawn from a population of 260 accidents to cars and vans in which at least one occupant was fatally injured. This sample has been fully described elsewhere by Griffiths et al (ibid). The 229 cars were selected so that a meaningful comparison could be made between the frequency of intrusion in the front and rear seating positions. Thus two-seater sports cars and vans were excluded from the analysis.

TABLE 14 SUMMARY OF ARU RESTRAINED CHILDREN CASES

Case No.	Vehicle	Other Vehicle or Object	Direction and Type of Impact	ETS km/h	Child Occupant Seat Position	Age Years	Sex	Injuries Location	Description	Severity AIS	Intrusion	Type	Comments
64	Renault R16	Hillman Minx	12 Distributed	50-60	OSR NSR	2 4	M F	Head Back	Small cut Bruise	1 1	None	Harness Guardian Angel	Harness held rear seat back when latches failed. 2 year old too young for harness. Caus of injury Unknown.
132	Mini	Bedford	6 Distributed		NSR	1	F	-	-	0	Rear seat cushion contacted rear of front seats	Seat Britax	
353	Capri 2000 GT	Unknown	12	20-30	NSR NSR	3 6½	M M	- Head	- Bruise	0 1	None	Harness Unknown	
590	Bedford Caravette	-	- Roll	-	Between FSP & driver's seat	1½	M	Head	Bruise	1	None	Seat Britax	Not fitted to manufacturer's instructions. Fell out of brackets during roll child landed on floor.
733	Mini	Buy Otter	12 Distributed	50-60	NSR	9mth.	M	Face	Cuts and Abrasions	1	In FSP at Dash and Footwell level	Seat Britax Star Rider	
754	Peugeot 403	Mini	6 Distributed		CR	4½	F	-	-	0	None	Seat Britax Star Rider	-
974	Triumph 1300TC	Mini	11 ½-½ overlap	15-20	Rear	1½	F	Face Chest.	Cut i eye Chipped tooth Strap burns on Chest	1	Small Footwell intrusion	Seat Britax	Either chin hitting chest or head striking the seat back.
1209	Triumph Herald 13/60 Estate	-	- Roll	-	NSR	1	F	-	-	0	None	Seat KL	
1335	Cortina III 1300L	Saab (i) Unknown (ii)	12 ½ overlap 6 Distributed	20-30	Rear	6mth.	M	-	-	0	Slight intrusion into driver's Footwell	Seat	-
1469	Mini	Cortina Mk 1 Estate	12 ½ overlap	50-60	NSR	1	M	Arm and shoulder Head	Friction burns Small cuts	1	Massive intrusion on driver's side. Intrusion at dash in FSP	Seat Britax Star Rider	Wrongly installed both top & bottom straps attached to top anchorage. Cause of injury friction burns due to webbing.
1705	Rover 3500	Austin A60	12 ½ overlap	35-45	OSR	1½	F	-	-	0	-	Seat KL	Restrained and unrestrained children in same vehicle.
1739	Vauxhall Chevette	Vauxhall Venture	12 ½ overlap o/s	25-33	CR	9 mth	M	-	-	0	Footwell intrusion on driver's side	Seat KL	Straps at large angles to centre line of vehicle allowing large forward movement.
1717	Hillman Minx	Motorway sign	9 Pole	-	NSR	1½	F	Head	Unconscious for 3 days	5	Intrusion of sign support split car in two. Floor panel distortion pushed FPS against rear seat cushion	Seat Kangol	Child's head contacted structure or back of front passenger seat.
1852	Austin 1300	AEC Marshall	2	-	OSR	2	M	Head	Slight bruise	1 Fatal	Intrusion at dash level on driver's side	Seat Britax	
2129	Cortina IV Estate	Hillman Saloon (i) Triumph Saloon (ii)	6 9	-	NSR	10	F	Serious injuries			Intrusion into rear luggage area & nearside FPS	Mothercare	Latches holding estate car seat back failed and released the seat back due to body distortion.
Portsmouth case	Cortina IV	Vauxhall Cavalier	1 Distributed	60-70	NSR	8mth.	F	-	-	0	4 cm at dashboard level	Seat KL	Restrained and unrestrained children in same vehicle. Unrestrained child probably contacted rear of front seat

In order to consider the application of this data to accidents in which child occupants are involved, a further sub-sample of 166 cases in which the accident occurred between 0600 and 2300 hours were selected. This time period is when children in the U.K. are most likely to be injured. It was found that the ratio I, reported in Table 15, was not significantly different between the two sub-samples of 166 cars and 229 cars. Hence the results of the intrusion study are considered applicable to child occupants.

The intrusion was estimated for the following 5 seat positions:- driver, front passenger, right, centre and left rear passenger. For each of these positions the intrusion was estimated at three levels in the vehicle:- the header rail, the dashboard and the footwell, as shown in Figs. 5 and 6.

The reduction of the SRDE in the direction of impact was estimated. The method used to estimate the intrusion differed slightly between cases involving frontal and sideways impacts. In frontal impacts (Fig.5) for the front passenger space, the distance between a vertical plane taken through the seat back and another vertical plane through the header rail and dashboard was divided into four equal parts. Thus if this distance was reduced by a quarter due to the dashboard moving rearwards, then the intrusion was defined as 25%.

FIGURE 5 DEFINITION OF ESTIMATE OF INTRUSION IN A FRONTAL IMPACT

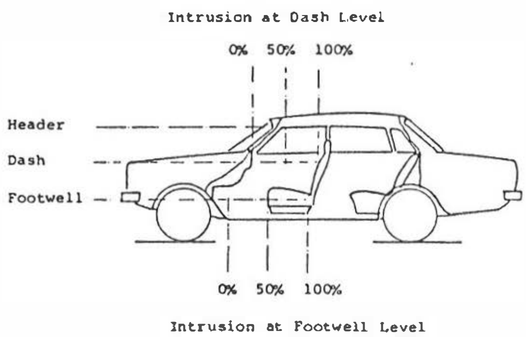
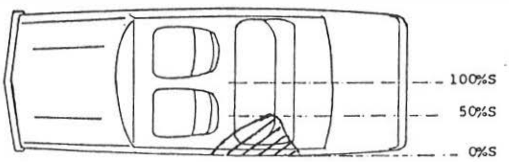


FIGURE 6 DEFINITION OF ESTIMATE OF INTRUSION FOR A STRUCK SEATING POSITION

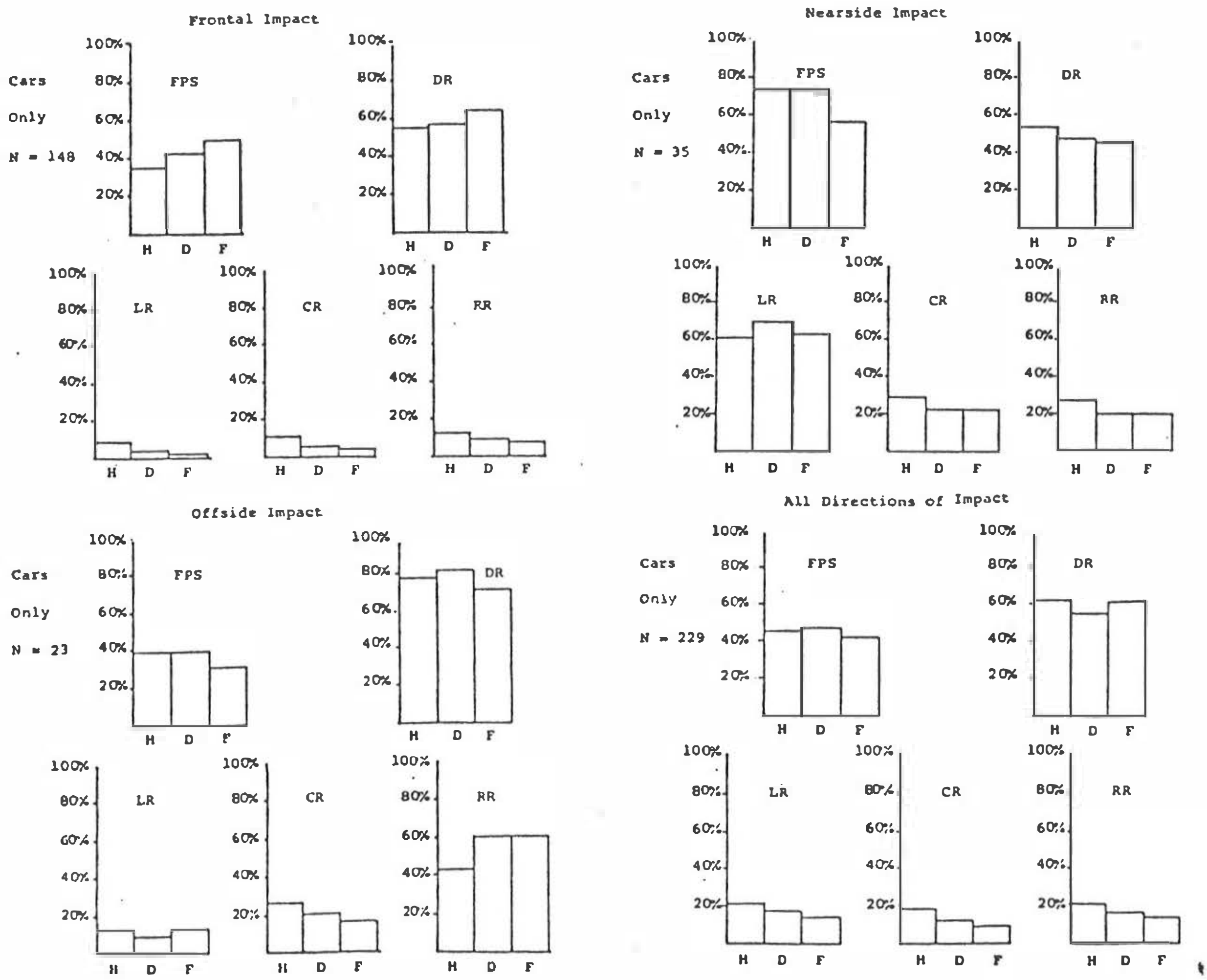


Note: 50% S means 50% of the seat width represents the limit of Intrusion.

In the case of intrusion at the footwell level, 75% intrusion implies that half the seat cushion has been intruded. A similar method was adopted for the rear seat spaces. Here the distance intruded in the direction of impact between a vertical plane drawn through the back of the front passenger seats and a vertical plane drawn through the rear seat squabs was estimated.

In side impacts for struck side seat position (Fig. 6) the ride-down distance was small or non-existent and the seating area was often intruded. Therefore, a slightly different method of defining intrusion was adopted. Two sub-categories of estimate have been used. Up to 100%, which indicates that the intrusion only entered the space initially between the car side structure and the seat. Secondly, a suffix S which indicates that the seat itself has been invaded in a lateral direction. For oblique impact directions of, say 2 o'clock, 25%S indicates that all the space in front of the seat cushion and 25% of the seat has been intruded. Characteristics showing the cumulative

FIGURE 7 FREQUENCY OF SOME DEGREE OF INTRUSION BY SEAT POSITION



Key

Seat Position			Level of Intrusion		
FPS	=	Front Passenger Seat	H	=	Header
DR	=	Driver's Seat	D	=	Dash
LR	=	Left Rear Seat	F	=	Footwell
CR	=	Centre Rear Seat			
RR	=	Right Rear Seat			

frequency of intrusion appear in full elsewhere (Roy 1980). These results have been summarised in Fig. 7, where the presence of some degree of intrusion in the different seating positions is described.

The incidence of intrusion in all seat positions for all directions of impact, is shown below:

Driver	- 60.7% header level	to	55.9% dash level	
Front Passenger	- 46.3% dash level	to	41.9% footwell	
Right rear	- 21.4% header level	to	15.7% footwell	
Left rear	- 21.8% header level	to	14.4% footwell	
Centre rear	- 18.8% dash level	to	9.2% footwell	

Of particular interest with respect to children is the intrusion at dashboard level, as this reduces the SRDE for a child's head in a forward impact. At dashboard level the frequency of intrusion in descending order was 55.9% driver, 46.3% front passenger, 17.9% right rear, 16.2% left rear, and 12.7% centre rear.

At all three levels there is a significantly lower ($p < 0.1\%$) frequency of intrusion in the three rear seating positions than in the front seating position. Comparison of the three rear seating positions with each other does not show such a clear picture. At the header level, there is no significant* difference between the left and centre rear positions. Both, however, had a significantly lower frequency of intrusion than the right rear seating position.

In a number of cases the seat back or seat runners failed. This failure might lead to additional loading being applied to the restrained child. Hence seats in the sub-sample with zero intrusion, no seat damage and no seat movement, represent the condition of maximum safety. The number of times in which the different seating positions exhibited this "safe" condition is shown in Table 15.

TABLE 15 % WITH ZERO INTRUSION AND NO SEAT MOVEMENT OR SEAT FAILURE

N = 229

Seating Position	%	Ratio I
Front Passenger	24.0	-
Driver	17.5	-
Right Rear	59.8	2.5
Centre Rear	66.8	2.8
Left Rear	60.7	2.5

$$I = \frac{\text{\% of given rear seat position with zero intrusion, seat movement, and damage}}{\text{\% of front passenger seat position with zero intrusion, seat movement and damage}}$$

*Throughout this paper, a 5% level of significance has been adopted, unless otherwise stated, χ^2 or Kolmogorov-Smirnov tests have been used as appropriate.

The analysis showed that the overall frequency of intrusion at dashboard level in the front passenger seat was 3.6 times that of the centre rear seat. If it is accepted that the performance of both forward and rearward facing restraint systems are compromised by intrusion, these data indicate that all such systems should by preference be fitted in the rear.

FAILURE OF FOLDING REAR SEAT BACKS IN ESTATE CARS AND HATCHBACKS

The analysis of ARU cases suggested that failure of the folding rear seat securing latches in estate cars and hatchbacks was common and could, under some conditions, lead to additional loads being applied to the child. Further, the European Draft Regulation for Child Restraints (R.172) does not require the child seat restraint to retain the vehicle seat back in an impact provided the seat back satisfies the vehicle seat regulation R.17. This is in contrast to BS.3254 - 1960 which does have a vehicle seat retention requirement.

In the files of the ARU it was noted that there were cases of vehicle seats which complied with R.17 failing. Therefore, an analysis of the performance of all the folding seat backs in vehicles in the files of the ARU was carried out. A total of 86 estate cars or hatchbacks which had folding rear seats and were involved in frontal impacts were selected. Of these, 55 vehicles had seats which complied with the requirements of R.17 and 31 had seats which did not comply with this regulation.

Method of Analysis. The vehicles were divided into two categories consisting of those which had seats which complied with R.17 and those that did not. Each of these categories was further sub-divided into those vehicles which carried an additional load, such as luggage, behind the rear folding seat, and those which did not. In addition a sub-sample of 69 vehicles were selected where the ETS was estimated equal to or below 50 km/h, and thus would be in the frontal impact velocity envelope envisaged within the philosophy of R.17.

The results are presented in Table 16. No significant difference was found in the E.T.S. distributions between those cars which complied with R17 and those which did not.

Performance. A statistical analysis of the results showed that when the seat backs were unloaded there was no significant difference between the performance of those seats which complied with R.17 and those which did not. It will be noted that 25% of the seat backs which complied with R.17 where the E.T.S. was below 50 km/h had latches which either partially or fully released the seat back. In cases where the seat backs carried a load behind them, the performance of the R.17 seats was worse, although this result cannot be assumed as a generalisation as it was not possible to identify the mass of each load. However, it is concluded that in frontal impacts, seats which complied with R.17 in the vehicles examined showed quite high release rates.

TABLE 16 DISTRIBUTION OF SEAT BACK FAILURE BY ECE 17 COMPLIANCE CATEGORY

Group 1 Total Sample - 86 Vehicles	Vehicle not to ECE 17 N = 31	Vehicles to ECE 17 N = 55
Unloaded		
Seats not released	15 (68.2%)	26 (70.3%)
Seats released (full or partial)	7 (31.8%)	11 (29.7%)
Loaded		
Seats NOT released	5 (55.6%)	2 (11.1%)
Seats released (full or partial)	4 (44.4%)	16 (88.9%)

Group II Vehicles with ETS ≤50 km/h - 69 Vehicles	Vehicles not to ECE 17 N = 25	Vehicle to ECE 17 N = 44
Unloaded		
Seats NOT released	13 (72.2%)	24 (75.0%)
Seats released (full or partial)	5 (27.8%)	8 (25.0%)
Loaded		
Seats NOT released	4 (57.1%)	2 (16.7%)
Seats released (full or partial)	3 (42.9%)	10 (83.3%)

CONCLUSIONS

These studies, although fragmentary, give some guidance from field accident experience on the appropriate factors which ought to be considered in modelling both restrained and unrestrained children.

1) The Safe Ridedown Envelope appropriate to the rear seating position of a car is approximately a parellelepiped of dimensions greater than base 508mm, width 1080mm, and slant height 826mm.

2) The injury pattern to 93 unrestrained children who received serious or fatal injuries showed that of the 81 children whose injury location was known, 76.5% had injuries to the head or face. Of the life-threatening injuries, 53.7% were located at the head and 22.0% on the torso.

3) Ejection of unrestrained children is a fairly common mechanism of injury.

4) In the UK the great majority of restrained children (>95%) travel in the rear sitting zone.

5) The age distribution of children using child seats corresponds to the range implied by the mass range specified in the British Standard (3254 - 1960).

For children using child harness systems however, 50% were younger than the minimum implied age of 57 months which corresponds to the lower mass range of the Standard.

6) Of restrained children receiving injuries, 63% had head injuries.

7) Questionnaire returns relating to restrained children, indicated that there were no neck injuries greater in severity than A.I.S.1. Neck injuries of A.I.S.1 represented 10% of those injured in seats and 4% of those in harnesses.

8) Questionnaire returns indicated that the causes of most injuries to children using restraints were the straps of the restraint systems or the teeth of the children causing lacerations of the mouth and lips.

9) In an ARU sample of accidents in which there was a fatal casualty (usually adult) the frequency of intrusion, and movement or seat mounting failure in the front passenger seat was approximately three times that of the centre rear seat position.

10) A separate analysis of frontal impacts involving estate cars and hatchbacks showed that in 44% of those cases the rear seat backs released either fully or partially. In accidents below an estimated ETS of 50 km/hr some 25% of rear seat backs failed, and there was no difference in those failure rates between seats which complied with R.17 and those that did not.

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