TRAUMA TO CHILDREN AS CAR OCCUPANTS

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ABSTRACT

A review is made of field data available on injuries sustained by child car occupants when involved in accidents. The results of a recent British study are presented. The performance of child restraint systems is considered by reviewing some experimental tests on child restraints, describing the results of tests carried out in the U.K. and presenting some case studies of accidents in which restrained children were present.

REVIEW OF ACCIDENT STUDIES

Moore et al. (1960) reported on injury patterns to child occupants of vehicles involved in rural accidents in America. A sample of 31,925 occupants of 14,520 vehicles was used; 9% of the occupants were children (age less than 12) and 16% were adolescents (age 12 - 14). It was found that children had a greater frequency of head injury, 77% of the injured children sustained a head injury, compared to 69% of the adolescents and 70% of the adults, but that although children sustained more head injuries the injuries were generally of a less severe nature. It was further noted that younger children were more likely to receive serious injuries than older children when injured.

A more recent report from Cornell (Kihlberg & Gensler 1967) considered the incidence of head injury in rural accidents. The sample consisted of 71,445 occupants of 33,831 vehicles. Children aged less than 10 yrs accounted for 7% (4,925) of the sample. They reported that children were less likely to be injured than an adult in the same seating position; table 1 gives details of the percentage injured by age and seating position. The younger child was found to be less likely to be injured than the older child but when injured to be more likely to receive a head injury. Rear seat occupants were less likely to be injured than front seat occupants. Although young children sustained head injuries more frequently than older children their injuries tended to be less severe. For front seat occupants the leading cause of injury for the younger child was the instrument panel, and for the older child the windscreen, whilst for rear seat occupants the back of the front seat was found to be the leading cause of injury for both age groups. Young children were more likely to receive cranial fractures and less likely to receive facial fractures than older children.

In both the preceeding studies the analyses were performed on data supplied by police forces. This approach to accident investigation produces a large amount of limited data suitable for gross statistical analysis. Another approach is the in-depth investigation, frequently at the scene, of a small number of accidents. The next two studies used this method.

Siegel Nahum & Appleby (1968) reported on the injuries received by child occupants in their in-depth studies of accidents in California. They defined a child as a person aged less than 13 yrs. Forty six accidents involving 82 children were used. Thirty four of the children were front seat occupants. The children were divided into three groups, the transition from one group to another corresponding to the major landmarks of a child's physical development, these being:

- when a child begins to sit up unsupported. This normally occurs at about nine months but for the convenience of analysis was taken as 1 yr.
- when a child's structure approximates to that of an adult and the child can sit in a normal car seat. This occurs at 4 - 5 yrs and was taken as 5 yrs.

Although the number of cases considered was small when compared to the previous studies reviewed the same points emerged. Children were more likely to receive head injuries than adults when injured. Rear seat occupants were less likely to be injured than front seat occupants. It was noted that for rear seat occupants younger children were more likely to receive serious injury than older children and it was suggested that this was because the younger child, with larger head, short lower limbs and higher centre of gravity than the older child, was more likely to pivot over the top of the front seat and strike the roof and windscreen. It was observed that lower limb injuries were more frequent amongst older children.

Robertson, Mclean & Ryan (1966) reported on the results of an at-the-scene study of accidents in Adelaide, Australia. A further report by Ryan (1968) considered in more detail injuries sustained by children. Achild was defined as age less than 15 yrs. The findings of the study were similar to the American findings. Ryan noted that a greater proportion of children under 5 yrs occupy the front seat than the rear seat. It was found that for front seat occupants children were injured less frequently than adults but that there was no difference in injury frequency for rear seat occupants. Head injuries were the most frequent injury sustained by children. Lower limb injuries were the next most frequent injury.

U.K. ACCIDENTS

The Sample

From accidents studied by the Accident Research Unit at Birmingham University a sample has been selected of vehicles in which at least one of the occupants was less than 15 yrs old and one of the occupants, not necessarily a child, was injured. This age grouping has been used because the definition of a child, as used in the national accident statistics in the U.K. is a person 'under 15 years of age' (D.O.E. 1973). The cases were collected using at-the-scene and retrospective in-depth investigations. The methodology of accident investigation at Birmingham has been described elsewhere (Mackay 1969). The sample consists of 103 vehicles containing 402 occupants of whom 178 were children. Figure 1 and table 2 give details of the accidents these children were involved in.

Occupancy

Table 3 shows the vehicle occupancy by total number of occupants and number of child occupants. The most frequent occupancy patterns were; one adult with one child, two adults with one child and two adults with two children. These three combinations accounting for roughly half the accidents whilst in the rest of the cases there were thirteen different occupancy patterns. There were four or less occupants in 67 (65%) of the cases.

Age and Seating Position

Sixteen (9%) of the children were less than 1 yr old, 51 (29%) were aged 1 - 5 yrs and 95 (53%) were aged between 6 and 14 yrs. In 16 cases the age was not known. Table 4 gives details of the age and sex of the casualties.

Ten (62%) of the sixteen children aged less than 1 yr were seated on the lap of another person; eight of these ten were seated on the lap of a front seat occupant. Two children were lying in carrycots; one of the carrycots was on the front seat and one in the back. One child was seated in a child safety seat in the centre of the back seat.

Six children in the 1 - 5 age group were using specially designed child safety harnesses mounted on the rear seats. Two thirds of the 51 unrestrained children in this age group were seated in the rear. Four of the nine children occupying front seats were seated on the laps of adults. One child was standing on the rear seat facing backwards.

In the 6 - 14 yr age group there were three children in restraint systems. Fifty nine (64%) of the 92 unrestrained children were seated in the rear. Two children were in the rear of an estate car behind the rear seats.

Details of seating position by age of the child are given in table 5.

Injuries to Unrestrained Children

Table 6 gives details of the location and severity of the injuries sustained by children of different ages in this sample. The severity of the injuries is described using the Abbreviated Injury Scale (States 1969).

Nine (60%) of the 15 unrestrained children less than 1 yr old were injured. Eight of the injured children sustained head injuries; three of these children sustained fatal head injuries and all three were seated on the laps of front seat occupants. One child received a facial injury. There were no other injuries to any other body areas.

Eight (18%) of the 45 unrestrained children aged 1 - 5 yr were not injured and in 5 cases details of the injuries were not known. Twenty six (81%) of the 32 injured children received head and face injuries whilst head and face injuries accounted for 67% of all injuries. All the life threatening or fatal injuries were head injuries. If minor injuries are excluded head and face injuries accounted for 72% of the injuries.

Of the 92 unrestrained children aged 6 - 14 yrs 78 (85%) were injured, 11 uninjured and in 3 cases details of the injuries were not known. The 78 injured received a total of 129 separate injuries of which 91 (70%) were minor injuries. Forty seven (60%) of the injured sustained head or face injuries and these injuries accounted for 52% of all injuries. If minor injuries are excluded head and face injuries accounted for 55% of injuries. The lower limbs were the next most frequently injured body area accounting for 29% of all injuries and 21% of non-minor injuries.

These results suggest that there are differences in injury patterns between children of different ages. However it must be remembered that the numbers involved are small and that the structure of the sample is such that rigorous comparisons between the injury patterns for different age groups is not possible. It is considered that these results are indicative but not necessarily representative of the experience of children in accidents in the U.K.

The following points emerge from the results.

As the age of the child increases the incidence of head and face injuries decreases from 100% of all injuries for children aged less than 1 yr, through 81% for children aged 1 - 5 yr to 60% for children in the 6 - 14 age group. Within the class 'head and face injury' the incidence of face injuries increases with age from 11% for the <1 yr age group through 58% for the 1 - 5 yr olds to 70% for the 6 - 14 yr age group.

When minor injuries are excluded the head emerges as the most frequently injured body area for any age. All life threatening or fatal injuries in the sample were head injuries.

The incidence of injuries to the extremities, i.e. upper and lower limbs, increases with age. For all severities of injury the percentage occurance of lower limb injuries was 0%, 16% and 49% for the $<$ 1 yr, 1 - 5 yr and 6 - 14 yr age groups respectively. The corresponding figures for upper limb injuries were 0%, 13% and 21%.

DISCUSSION

The accident studies reviewed in the previous sections and the results of the study of U.K. accidents have shown that there are differences in injury patterns between children of different ages. Part of this difference can be attributed to the variations in seating position distributions between the different age groups. For example, infants frequently sit on the lap of the front seat passenger; 50% of all children $\leq$ 1 yr old were seated in this position. A high proportion of children aged 1 - 5 yr occupy the rear seats; approximately 70% of the U.K. sample occupied the rear seats.

The greater occurance of head injury in children can be explained by the anatomical differences between children and adults. At birth the head accounts for 25% of the body length whereas in an adult it accounts for only 14% of body length. Thus the increases relative size of a child's head makes it more likely to impact another object in an accident. The heavier head mass of a child and the higher centre of gravity of a seated child results in a different impact trajectory for the younger child. The changing relationship between head and face injury as the child grows older can be attributed to the variation of facial area to total head area with age. At birth the face to cranium ratio is approximately 1 : 8 whereas that of an adult is 1 : 2½

CHILD RESTRAINT SYSTEMS

The provision of effective restraints for children is complicated by the fact that children are developing adults and consequently the restraint systems used for adults, the major users of cars, are not suitable for children. Because a child develops quickly in the early years the correct restraint at one age is not necessarily the correct restraint at another age. It is an accepted fact that restraining forces on a human body should act on the strongest parts of the body, i.e. the skeletal frame. However the thickness of the fatty tissue on young children makes it difficult to locate restraint straps correctly over the child's pelvis in particular. The rapid growth and change in body proportions of the young child means that the position of the restraint straps must be frequently changed if they are to remain in the correct position. The problem of correct positioning is further complicated by the different shape of the child's developing skeleton. For instance the absence of the anterior superior iliac spines on a child's pelvis means that a lap strap can more easily ride up onto the abdomen which could result in severe injury to the abdominal viscera.

A large number of devices have been marketed throughout the world for use by children in cars. Common to all these devices is the provision of a seat or harness more suitable for use by a child than the normal car seat or seat belt. Not all these devices however are effective as restraint systems.

Appoldt (1966) reported on the performance of seven different child restraints tested in frontal and 60° angled impacts. He noted that dummy decelerations exceeded sled decelerations in all cases and that all the devices showed a lack of lateral restraint. He recomended that restraint straps should be designed to provide lateral support and should be adjusted in use to be as tight as possible. He suggested that all restraint systems should be subject to dynamic testing.

Tests carried out at the Highway Safety Research Institute (H.S.R.I.) at Michigan (Robbins et al. 1970) investigated the effectiveness of various child restraint concepts. They reported on 37 different child seat and harness designs tested in frontal, oblique, side and rear impacts. Summaries of each test were given with details of impact velocity, deceleration, head and chest accelerations, belt loads and travel of the dummy from normal seating position. It was found that a number of seats were not adequately restrained: seats which relied on hooks over or under the car seat back became detached from the car seat and flew. Lack of structural integrity was a problem with many of the seats; the tubular structures from which the seats were made being unable to stand up to the loads placed on them. A general failing was the lack of lateral restraint. As a result of these tests five points were stressed for consideration in the design of child restraints:

- structural integrity of the child's seat
- effect of dynamic interaction of the child seat and the car seat
- attachment of the child seat to the vehicle
- limitation of the movement of the child in an accident
- distribution of the restraining forces on the child

A further series of tests at H.S.R.I. (Roberts & McElhaney 1973) showed that, although there had been improvements in child restraint design in America, most of the devices available did not offer protection comparable to that offered to adults. They found that there was excessive head travel, in both front and side impacts, with most of the devices tested and that injurious head contacts with the interior of the vehicle were likely. Concern about the design of restraint straps was expressed and it was noted that the use of upper torso restraints attached to the lap belt without the provision of a crotch strap resulted in the lap belt moving from the pelvis to the abdomen in a frontal impact. Tests on prototype seats developed at H.S.R.I. showed that it was possible to design effective restraint systems. However details of these seats were not given. It was suggested that a child's lap belt should be at an angle of 45° - 60° to the horizontal to lessen the chance of the belt loading the abdomen.

A further series of tests on a British child safety seat showed that it was an effective restraint system; it's performance being similar to that of the H.S.R.I. prototype toddler seat. In the side impact test the seat was the best tested, the side excursion of the dummy head being less than that experienced with the H.S.R.I. seat. (Rothman 1973)

Tests on child restraint systems at the Traffic Accident Research Unit (T.A.R.U.) in New South Wales, Australia confirmed the dangerous nature of the 'hookover' type of seat, suggesting that a child in such a seat would most likely sustain fatal injuries in any accident at a speed of 20 mph (32 km/h) whereas a properly designed child safety seat will protect children from injury at 30 mph (48 km/h). (Autosafe 1972)

Herbert et al. (1973) reported on further tests at T.A.R.U. which concentrated on systems which had the approval of the Standards Association of Australia. Five different systems were tested in front, side and angled impacts and were tested with the restraint straps tight and slack. Movement of the dummy from rest position and peak webbing loads were measured. It was concluded that the layout of the harness straps and the general design of the seat frame can have a significant effect on submarining. The lower torso restraint must be carefully designed to prevent movement of the belt from the pelvis onto the abdomen and that although proper location of the lap strap is assisted by the presence of a crotch strap it is not essential. A badly adjusted crotch strap can be a source of injury to the genitalia. The use of cushions to raise the seated height of a child using a harness was not recommended as it can promote dangerous submarining.

Consideration of the physical development of a child leads to the identification of three stages of child development which each require different solutions to the problems of restraint. These are:

- from birth until the child is capable of sitting up unaided, this normally occurs when the child is about nine months old.
- from nine months old when the child is capable of sitting up but is too small to sit in a conventional car seat, until the child is big enough to sit in the normal seat. This normally occurs between the ages of 4 and 5 yrs.
- From about 5 yrs when the child can sit in a conventional car seat but has not developed sufficiently to use a standard adult restraint until the child is of sufficient stature to use an adult restraint system.

In the U.K. the British Standards Institute (B.S.I.) has defined standards appertaining to child restraint systems (B.S.I. 1970). They recognize the problems of child restraint design that have been mention previously and have divided child restraints into groups according to the weight of the child for which they are designed. The groups are virtually identical to the three stages of child development outlined above but weight was chosen rather than age as there are great variations in weight and stature for a given age. The groups used are;

- children weighing from 20 - 40 lbs (9 - 18 kg)
- children weighing from 40 - 80 lbs (18 - 36 kg)

The performance criteria for each group was:

'that the accident conditions will impose a maximum loading on the complete assembly equivalent to twenty times the weight of the wearer for the child restraint and twenty times the weight of the seat for the seat restraint both divided parallel to the longitudinal axis of the car.'

The reference to seat restraint was included as it was recognised that:

'for safe use of a child restraining device it is essential that the car seat itself should be restrained from forward movement in the event of an accident.'

Testing of restraint systems for B.S.I. approval is carried out both dynamically and statically but in both cases the test procedure only calls for the device to be subjected to a frontal impact. No testing of the restraint system in side or rear impacts is made. The location of the restraint straps on the child's body is not stipulated.

EXPERIMENTAL TESTS

A series of tests were carried out for the Automobile Association to evaluate the performance of child seats and harnesses available in Britain and sold as suitable for children weighing from 9 - 18 kg (age 1 - 5 yr). The tests were designed to show the performance of the various systems in frontal impacts for use in a popular magazine (Drive 1973). The tests were qualitative rather than quantitative.

The rear nearside quarter of a Ford Cortina Mk 111 was mounted on an impact sled and the child seat or harness fitted according to the manufacturer's instructions. They were then subjected to a 20g stop from 20 m.p.h. (32 km/h) using a Sierra 'Toddler' dummy to simulate a child occupant. A high speed (2000 frames/sec) film record of each test was made.

Six of the seats tested were of the folding chair type. Figure 2 shows an example of this type of seat. The design of the seat is such that they rest on the car seat and there is an extension to the base of the seat which clips under the base of the car seat back. Three of the seats also had a metal bracket which hooked over the top of the seat back. The child is strapped in the seat by straps attached to the child seat. In all cases the seats became detached from the car in the impact test allowing the child seat and dummy to go into free flight.

Two of the seats were shell type seats anchored to the vehicle at two points only. One of the seats was provided with metal clips at either side of the base of the seat which clipped onto an adult lap belt. In the test one of these clips deformed and the seat became detached on that side from the lap belt allowing it to twist and the dummy to contact the interior of the car. The dummy was restrained in the seat by a lap diagonal belt system and this would have been an inadequate restraint had the seat anchorage clips held. The second seat used purpose designed straps to anchor the base of the seat and these proved to be effective. The dummy was adequately restrained in the child seat by a four point harness, but the lack of anchorage straps at the top of the seat allowed the top of the seat and consequently the dummy's head excessive forward movement.

One of the harnesses tested fitted around the chest and shoulders of the child and was free to slide up and down two straps anchored to the floor and parcel shelf of the car. It was claimed that this allowed the child to sit, stand or sleep in comfort. The system was tested in both the standing and seated position (Figure 3). The harness did not apply any restraint to the lower part of the dummy's body; all the loads being taken under the armpits and around the upper part of the chest. There was considerable forward movement of the dummy. In the standing position the friction produced by the relative motion of the harness and vertical restraint straps was sufficient to melt the webbing.

None of the systems described in the preceeding paragraphs had B.S.I. approval. Four seats having B.S.I. approval were tested.

One was a high folding chair used in conjunction with a harness which anchored the chair as well as providing restraint for the child. In the test the harness rode up onto the dummy's abdomen and there was sufficient stretch in the system to allow the dummy considerable forward movement and contact with the 'safety rail' of the seat which was at stomach level.

The other three B.S.I. approved seats were all similar in design concept being shell type seats attached to the vehicle by four straps, two from the base of the seat to the floor of the car and two from the top of the seat to the rear parcel shelf. The child was restrained in the in the seat by a five point harness. An example of this type of seat is shown in figure 4. All three seats provided good restraint in the impact tests, the deceleration forces being distributed over the dummy's shoulders, chest and pelvis.

Two harnesses, designed for and only having B.S.I. approval for use by older children (18 - 36 kg), were tested as they were sold by shops as suitable for use by younger children. In one test the dummy was seated on a cushion to raise the seated height, whilst in the other test the dummy sat directly on the car seat. In both tests the dummy submarined, the harness riding up onto the abdomen and chest; when seated on a cushion the cushion shot out from under the dummy at an early stage allowing it to drop and thus introduce more slack into the system.(Figure 5) There was considerable forward movement of the dummy in both tests.

CASE STUDIES

Five accidents are briefly presented to illustrate the performance of child restraints. The damage to the vehicles is described using the Vehicle Deformation Index - V.D.I. (S.A.E. 1972) and the severity of the accident is described using the concept of Equivalent Test Speed - E.T.S. (Mackay and Ashton 1973).

Accident No. 64 Renault 16 V.D.I. 12FDEW3

The case vehicle struck the side of another car. The E.T.S. was estimated at 40 - 50 km/h. The driver and the front seat passenger were wearing inertia reel lap diagonal belts. The two rear seat occupants a 2 yr old male and a 4 yr old female were restrained in four point harnesses. The driver a 38 yr old male sustained minor injuries. The front seat passenger a 40 yr old female received serious head injuries when her seat belt broke at the 'B' pillar swivel. The two children sustained only minor bruises and abrasions from the webbing of the harnesses.

Accident No. 353 Ford Capri V.D.I. 01FZEW2

This vehicle struck the side of another car. The estimated E.T.S. was 20 - 30 km/h. There were four occupants in the vehicle all restrained. The driver and front seat passenger were wearing static lap diagonal belts and sustained minor bruises from the belts. The rear seat occupants a 7 yr old male and a 3 yr old male, both of whom were using child harnesses, sustained minor bruising.

In these two accidents three of the children were restrained by harnesses which were not designed for the age of the child using it, but for an older child. It is of interest that a 2 yr old male using one of these harnesses in a severe accident only received minor bruises.

Accident No. 540 Bedford Caravette V.D.I. 00XDA01

The case vehicle went out of control after mechanical failure of the steering and was involved in a complex sequence of events involving a glancing blow with another car, impacts with a fence and hedge and a 360^{o} roll. The driver a 35 yr old female and the front seat passenger a 29 yr old male were wearing static lap diagonal seat belts and were uninjured. In the rear of the vehicle were a 63 yr old male and a 62 yr old female neither of whom were restrained. They both received extensive bruising and abrasions. Of particular interest was the fifth occupant a 21 month old baby boy who was seated in a shell type child seat. The child seat was not mounted in the vehicle according to the manufacturer's instructions but was fixed to two bars which had been fitted by the owner across the back of the front seats, the child sitting between the front seats. During the accident events the bars became detached from the seats allowing the child seat and child to be thrown around inside the vehicle. The child sustained a bruise to the back of the head.

This accident illustrates the importance of correct fitting of child restraint systems

Accident No. 720 Austin 1100 V.D.I. 03RPHN5

This vehicle went out of control, left the road and struck a large tree with the offside of the vehicle. There was considerable intrusion of the side structure into the passenger compartment. The four occupants of the vehicle were all restrained. The driver a 38 yr old male sustained minor concussion, multiple fractures to 3 ribs on the right side and abrasions to his hands; the head and chest injuries being due to contact with the intruding side structure. The front seat passenger, a 38 yr old female, was uninjured. Both the front seat occupants were wearing static lap diagonal belts. The two rear seat occupants, a 12 yr old girl on the nearside and a 9 yr old boy on the offside were restrained by single diagonal belts, not special child harnesses. The boy sustained severe head, chest and abdominal injuries, which proved fatal, from contact with the intruding side structure. The girl received a laceration to the right eyelid and abrasions to the right side of the face, right hand and both knees.

The use of single diagonal belts which provide little side restraint, rather than child restraints, contributed to the severity of the injuries. Adequate side restraint would have prevented the injuries sustained by the nearside rear occupant and probably have lessened the severity of the offside rear occupant's injuries.

Accident No 733 Austin Mini V.D.I. 12FDAW5

This vehicle was involved in a severe frontal impact with a heavy goods vehicle. The estimated E.T.S. was 50 - 60 km/h. The driver a 26 yr old male and the front seat passenger a 25 yr old female were both wearing static lap diagonal seat belts. The driver sustained fractures to the left forearm and hand, left tibia and fibula and to the nasal bones. He also received severe head injuries and died 54 days after the accident without regaining consciousness. The front seat passenger sustained abrasions to her face and fractures of the right humerous, right femur and left foot. There was massive intrusion of the bulkhead into the front seat occupants seating area. The third occupant was a 9 month old baby boy seated in a B.S.I. approved shell type seat mounted in the centre of the rear seat. His only injury was a small cut to the chin. There was no evidence of any neck injury.

DISCUSSION

Children aged less than 1 yr old (weight less than 9 kg)

Siegel et al. (1968) and Rogers & Silver (1968) both recommended that the child should be placed in a carrycot, the carrycot placed on the rear seats of the car and anchored by placing the existing adult lap belts through the frame of the cot. It was noted that this was a temporary measure until more effective restraints were developed.

Special carrycot restraints are market by a number of firms in the U.K. With these the cot is placed along the rear seat and is anchored by straps which pass over and around the cot and are fixed to the vehicle floor and rear parcel shelf. The effectiveness of this system depends on the construction of the carrycot; a weak cot could deform in an accident and impair the performance of the restraint.

General Motors have designed a special 'infant carrier' which is said to be more effective than a conventional carrycot. (Sierant 1969, Feles 1970) It consists of a specially shaped carrycot in which the child is strapped in a semi reclining position. Two handles on the cot are used for carrying and also for restraining the cot; the cot is placed on a car seat in a rearward facing position and the adult lap atrap passed through the handles. Impact protection is claimed to be good. The American consumers association rated this restraint the best availabe for the young child (C.A. 1972). However it is of limited use in Europe as a separate lap belt is a prerequisite for the use of this system.

Children aged 1 - 5 yrs old (weight 9 - 18 kg)

This age group has the widest variety of systems available and there are large differences in the protection offered by the different systems. They can be divided into three main groups - vests, harnesses and seats. An early Ford device consisted of a vest which the child wore and to which straps were attached which clipped onto an adult lap belt. The Ford vest was marketed in three sizes (Fredericks 1969). The concept of a vest restraint is good in that the loads are distributed over the widest possible area but has the disadvantage that it is non adjustable and would soon have to be replaced as a child grew older. For this reason an adjustable harness in which the loads are spread over the greatest possible area by the use of shoulder and lap straps offers advantages over a vest system. Impact tests have suggested that the use of a harness alone for children in this age group is not advisable as the pelvis of a child lacks well defined iliac crests, which act as anchor points for the lap belts in adults, and thus the lap section is more likely to ride up onto the abdomen. However in the accidents seen in which there were young children of this age group using harnesses there was no evidence of abdominal injury. An important consideration in the design of a restraint system is comfort. The short legs of a young child make the normal car seat unsuitable and an auxillary seat is needed to provide a more suitable seating position. The use of a booster cushion with a harness is unsuitable because the cushion is likely to fly out from under the child at an early stage in the accident. The folding high seat has been shown to be generally unsuitable as a safety seat. The most effective type of system is a shell type seat which is anchored to the car structure by four restraining straps, two from the base of the seat to the floor of the car and two from the top of the seat to the rear parcel shelf. The child is secured in the seat shell by a five point harness consisting of two shoulder straps, a lap strap and a crotch strap. It is important that the child restraint straps are as tight as possible and the lap strap is low down on the pelvis.

Some concern has been expressed that, due to the larger head mass and weak neck of a young child neck injuries may occur and therefore some form of head restraint should be provided. One method is to provide a countered impact surface in front of the child so that the child wraps around it in an accident distributing the restraining forces over the whole of the body and excessive relative motion of the head and chest are prevented. (Heap & Grenier 1968, Fredericks 1969). Another way of providing adequate head restraint is to use a rearward facing seat. Aldman (1966) described a Swedish seat that used this principle. However it has been suggested (Herbert et al. 1973) that head restraint is unneccesary in frontal impacts as the chin impacting the manubrium sternum provides safe deceleration of the head. The case study presented in which there was a 9 month old baby in a child safety seat supports this view.

Children greater than 5 yrs old (weight 18 - 36 kg)

It was suggested by American researchers (Siegel et al. 1968, King et al. 1969) that children of this age should use a normal adult belt with a firm cushion to provide better belt positioning, although King et al did stress that this was only recommended until better systems were developed. Purpose designed harnesses are available in the U.K. and accident experience suggests that the protection provided to children by these systems is at least equal to that offered to adults by lap diagonal belt systems.

CONCLUSIONS

Previously published work suggests that for unrestrained children:

- younger children are less likely to be injured than older children but that when they are injured they are more likely to sustain a head injury. The severity of head injuries sustained by younger children is generally less than that sustained by other age groups.
- the lower limbs are the next most frequently injured body area and that the frequency of lower limb injuries increases with age of the child.
- rear seat occupants are less likely to be injured than front seat occupants.

The present field study has found that for unrestrained children:

- the head was the most frequently injured body area no matter what the age of the child.
- as the age of the child increases the overall incidence of head injury decreases and the incidence of injuries to the face increases.
- there was an increase in the incidence of upper and lower limb injuries with age; lower limb injuries being more frequent than upper limb injuries.
- all life-threatening or fatal injuries were head injuries.

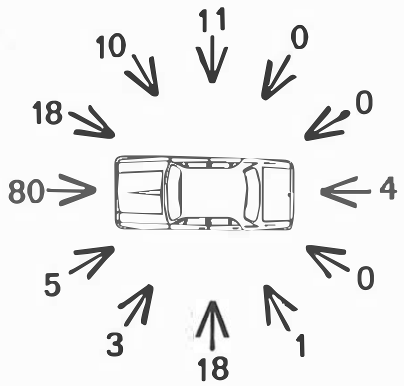
For restrained children the available accident data suggests that:

- children wearing the correct BSI approved child restraint system are provided with protection equal to that offered to an adult by a lap diagonal belt.

Test work on currently available child restraint systems shows that:

- it is important that a child restraint system is adequately anchored to the vehicle structure.
- for children weighing nine to eighteen Kilograms (age about 1-5 years) the most effective system is a shell type auxillary seat anchored to the vehicle at four points and provided with an integral child harness.
- the structure of a child's pelvis is such that either a relatively steep lap belt angle ($45-60^{o}$) or the provision of a crotch strap is necessary to ensure correct location of the lap belt.

FIGURE 1 DIRECTION OF IMPACT FORCES - BIRMINGHAM STUDY



ROLLOVER 11

COMPLEX 10

NOT KNOWN 7

28

150

TABLE 1 SEVERITY OF IMPACT - BIRMINGHAM STUDY

IMPACT DIRECTION	EQUIVALENT TEST SPEED km/h 0-10	11-20	21-30	31-40	41-50	51-60	N.K.	TOTAL
11, 12, 01.	9	20	31	17	15	5	6	103
10. 02.	0	0	2	3	2	0	4	13
03, 04, 08, 09.	1	15	10	1	0	0	3	30
05, 06, 07.	2	0	2	0	0	0	0	4
								150

TABLE 2 FREQUENCY OF INJURY - after Kihlberg and Gensler 1967

AGE	NO. OF OCCUPANTS FRONT	NO. OF OCCUPANTS REAR	% INJURED FRONT	% INJURED REAR	% HEAD INJURY FRONT	% HEAD INJURY REAR
0 - 4	1094	1190	59.2	42.8	87.3	76.6
5 - 9	835	1806	66.2	51.3	82.7	72.8
10 +	22057	10632	81.4	62.2	70.2	56.9

TABLE 3 VEHICLE OCCUPANCY - BIRMINGHAM STUDY

NUMBER OF CHILDREN	TOTAL NUMBER OF OCCUPANTS 1	2	3	4	5	6	7	TOTAL NO. OF CASES	TOTAL NO. OF CHILDREN
1		18	17	8	9	2		54	54
2			6	16	10	1		33	66
3				2	4	3		9	27
4					1	3		4	16
5						2	1	3	15
		18	23	26	24	11	1	103	178

TABLE 4 . AGE AND SEX OF CHILD OCCUPANTS - BIRMINGHAM STUDY

AGE	M	F	N.K.	TOTAL
1 yr	8	3	5	16
1 - 5 yr	22	25	4	51
6 - 14 yr	41	48	6	95
N.K.	2	1	13	16
				178

TABLE 5 SEATING POSITION BY AGE - BIRMINGHAM STUDY

SEATING POSITION	AGE OF CHILD < 1 yr	1 - 5 yr	6 - 14 yr
In Restraint System	1	6	3
Front Seat	2	5	26
On Lap of Front Seat Passenger	8	4	1
Rear Seat	2	28	59
On Lap of Rear Seat Occupant	2	2	0
Other	0	1*	2**
Not Known	1	5	4

NOTE * standing on rear seat facing back ** in rear of estate car behind seat

TABLE 6 LOCATION AND SEVERITY OF INJURIES SUSTAINED BY UNRESTRAINED CHILDREN

a) Children aged < 1 yr

BODY AREA	SEVERITY OF INJURY (AIS) 01	02	03	04	05	06	ALL
HEAD	5					3	8
FACE		1					1
NECK							0
CHEST							0
ABDOMEN							0
ARMS							0
LEGS							0
BACK							0
SHOCK							0
							9

INJURED	9
NOT INJURED	6
INJURY N.K.	0
	15

b) Children aged 1 - 5 yr

BODY AREA	SEVERITY OF INJURY (AIS) 01	02	03	04	05	06	ALL
HEAD	4	6	1	2		1	14
FACE	12	3					15
NECK							0
CHEST							0
ABDOMEN	2						2
ARMS	2	1	1				4
LEGS	2	2	1				5
BACK	1						1
SHOCK	2						2
							43

INJURED	32
NOT INJURED	8
INJURY N.K.	5
	45

c) Children aged 6 - 14 yr

BODY AREA	SEVERITY OF INJURY (AIS) 01	02	03	04	05	06	ALL
HEAD	17	11	3		1	3	35
FACE	30	3					33
NECK	2						2
CHEST		1					1
ABDOMEN	1		1				2
ARMS	10	5	1				16
LEGS	30	6	2				38
BACK			1				1
SHOCK	1						1
							129

INJURED	78
NOT INJURED	11
INJURY N.K.	3
	92

FIGURE 2

FOLDING HIGH CHAIR
NOT B.S.I. APPROVED

FIGURE 3

CHILD HARNESS
NOT B.S.I. APPROVED
AFTER IMPACT TEST

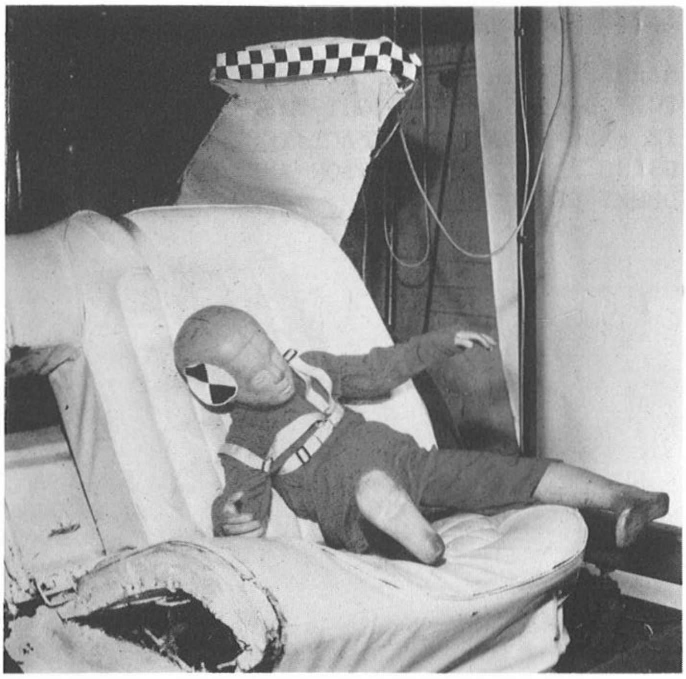
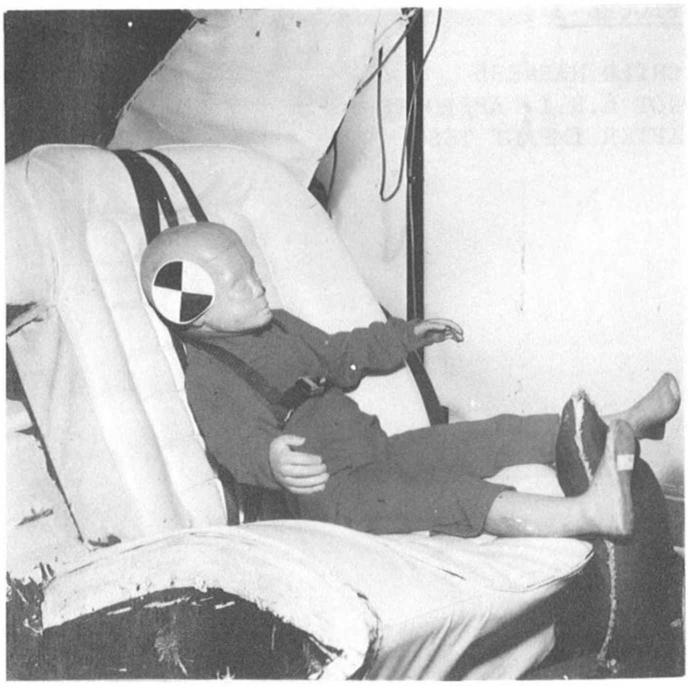


FIGURE 4

SHELL TYPE SEAT WITH HARNESS
B.S.I. APPROVED FOR CHILDREN
IN WEIGHT RANGE 9 - 18 kg

FIGURE 5

HARNESS WITH B.S.I. APPROVAL
FOR CHILDREN IN WEIGHT RANGE
18 - 36 kg AFTER IMPACT TEST
USING AUXILLARY CUSHION AND
DUMMY WEIGHT 14 kg



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