CHILDREN IN CARS - THEIR INJURY RISKS AND THE INFLUENCE OF CHILD PROTECTION SYSTEMS

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German Association of Third Party, Accident, Motor Vehicle and Legal Protection Insurers

Twelfth International Technical Conference on Experimental Safety Vehicles (ESV)
Göteborg, Sweden
May 29 - June 1, 1989
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ABSTRACT

In this paper the injury risks to children in cars with and without protection are analysed according to age groups and accident characteristics such as collision types, severity of the accident, damage to the car, accident opponent etc. To this end comprehensive accident material involving children in cars has been established: a large-scale campaign with one of Germany’s major newspapers was organised, and it produced more than 3,300 reports of car accidents involving protected and unprotected children in 1988. The parents were questioned; as far as possible, a retrospective accident evaluation was carried out. Observations on biomechanical tolerance limits according to the child’s age are discussed. It was ascertained which parts of the body sustained especially critical injuries, broken down according to their type and frequency. The safety effect of child protection systems was confirmed; their use, depending on the type of protection system, was analysed with regard to the children’s weight. Recommendations are given for the further development of child protection systems in order to reduce the biomechanical loads, avoid incorrect operation and optimise the protection criteria.

THE PRESENT SITUATION IN GERMANY

About 100 children are killed and some 11,500 injured as car passengers in Germany each year /1/. Although the children killed make up only a proportion of about 2.5% of all car occupants killed, this must be compared with their mileage - and thus their risk
Figure 1. Children killed in cars (0-14 years) and rate of children using a restraint system in Germany.

exposure - and it seems that especially in their case a further reduction in the accident figures is easily possible, since even today the rate of children using a restraint system in cars is only between 50 and 60% (Figure 1) /2/. A substantial increase in the total rate of those using a restraint system was only recorded from 1985 to 1986 with a rise of 31% to 51%, and in this period the number of children killed in cars declined from 117 to 90.

If the rate of children using special child restraint systems is examined (Figure 2), it emerges that this rate has remained fairly constant for 3 years; the tendency to restrain children by means of 3-point belts has also remained the same since September 1986. So at the present time we have between 40% and 50% of children not using a restraint system in cars, a situation which is extremely unsatisfactory.

The aim of this paper is to show to which risks children using restraint systems and not using them in cars are exposed, where the focal points of injury are to be found, how children's restraint systems are used and where areas for further improvement in child restraint systems emerge.
Figure 2. Rate of children using special child restraint systems and usage rate of 3-point belts on the rear-seats of cars

DESCRIPTION OF THE ACCIDENT MATERIAL

At the beginning of the ’70s the HUK-Verband carried out the first studies on the subject of injuries to children in cars /3,4/; the car accident material at that time contained - apart from a few isolated cases - only children not using a restraint system.

By means of newly compiled material (more than 3,500 car accidents with personal damage from the year 1980 and after) with children using (n = 135) and not using (n = 302) a restraint system it was possible in the ’80s for the first time - by making a direct comparison - to make an assessment of the reduction in injuries that would result from the use of child restraint systems /5,6/.
Compiling large-scale material of accidents with children not using - and especially using - restraint systems was impeded in the past, and still is today, by some important factors; these include in particular that

- car accidents in which children in the car are injured are relatively rare,
- a direct access to car accidents with children in the cars is not possible through insurance cases,
- in the past the rate of children using restraint systems in cars was relatively low and therefore it was especially difficult to obtain information on restrained children.

For this reason the HUK-Verband's accident research sought new ways of compiling extensive large-scale material which was adequately extensive: to this end, in the course of a large-scale campaign entitled "The Safety of Children in Cars" detailed articles on this subject were published in a major German newspaper over several weeks in 1988. The campaign was combined with a competition in which the parents had to answer questions on the subject of children's safety and, at the same time, were given a chance to report to the HUK-Verband's accident research accidents they had experienced with children using and not using restraint systems in cars. The parents who took part in the competition were sent an extensive questionnaire which had been compiled in cooperation with psychologists, engineers and doctors, and were asked to describe their accident as accurately as possible.

Altogether 3,300 parents were written to, and of these almost 1,000 filled in the questionnaire and sent it back to the HUK-Verband's accident research. Accidents with inadequate information or non-crash events were eliminated, so that in the end 870 accidents were available for a detailed evaluation. In the 870 vehicles involved in accidents (861 cars/station cars, 2 convertibles, 7 small buses or small goods carriers), there were a total of 1,153 children aged from 0 to 12 years, 288 of whom were not using a restraint system and 865 who were.

The accidents involving children not using a restraint system were concentrated in the '70s/'80s, and those involving children using these systems in the '80s, with most accidents in 1987 (125 accidents).

The following descriptions and diagrams (accident opponents, impact areas, degree of damage) always refer to "accidents and/or vehicles in which at least one child was restrained or was not".
Distribution of the accident opponents

The distribution of the accident opponents shows the same ranking order for both restrained and unrestrained children: car/car accidents are most frequent (65-75%), followed by single car accidents (15-20%), car collisions with trucks and buses (5-10%) and other collisions (about 5%). Differences only arise insofar as the "car" occurs more frequently as an accident opponent in the case of restrained children than unrestrained, but the single-car accident is rarer.

Distribution of the impact areas

The distributions of the main impact areas on the cars with children is shown in Figure 3: it is most frequently the front which is damaged (51.3%), followed by damage to the rear (22.8%), the left-hand side (13.5%) and the right-hand side (10.1%); damage to the whole vehicle in roll-over accidents accounts for 2.3%. Figure 3 also indicates the frequency of damage to the separate areas front, side and rear.

Degree of damage

Figure 4 shows the frequency of the degrees of damage 1-5 (the degree of damage 3 is equal to running into a wall at about 50 kph). It was possible to ascertain the degree of damage for those vehicles for which photographs of the damage were available (191 = 22%). The distribution shows that the vehicles concerned were involved not only in light collisions, but that serious and extreme damage also occurred; thus a degree of damage 3-5 applied to 63 of the 191 vehicles.
Figure 3. Distribution of the impact areas on the car, total material
INJURIES TO RESTRAINED AND UNRESTRAINED CHILDREN IN CARS

Unrestrained children (n = 288)

Age distribution

The age distribution for the unrestrained children is presented in Figure 5. There were 45 four-year-old children, who thus represented the largest group, followed by the five-year-olds with 40.
Figure 5. Age distribution of unrestrained children in cars

Age and sitting position

The sitting position of 285 of the 288 unrestrained children was known (Figure 6); 13 children (4.6%) were sitting on the right-hand front seat, 107 (37.5%) on the right-hand rear seat, 88 (30.9%) in the middle of the rear seat and 77 (27.0%) on the left-hand rear seat.

The age distributions in the above-mentioned sitting positions show very great differences among themselves and also deviate from the global age distribution (see Figure 5). Only children sitting in the middle of the rear seat have a distribution which corresponds to the tendency shown in Figure 5.
Figure 6. Sitting position and age of unrestrained children in cars.
Distribution of injury severity and age

The distribution of the injury severity MAiS for all 288 unrestrained children is presented in Figure 7: there remained 140 children (48.6%) uninjured; 148 children (51.4%) sustained MAIS 1-6 injuries. The proportion of injury severity MAIS 2-6 was 10.1%. It can be seen that serious/fatal MAIS 3-6 injuries dependent on age are to be found in all age groups, and even 0/1-year-olds often sustain serious injuries.

Distribution of injury severity and collision type

The maximum injury severity (MAIS) dependent on the type of collision was known in the case of 255 children. An important finding is that serious or critical injuries occurred only in head-on or side collisions in the study material.

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Figure 7. Distribution of the injury severity MAIS and of the age of unrestrained children in cars
Individual injuries to the various parts of the body

**Head-on collisions**. In the case of 67 children sustaining AIS 1-6 injuries (impact area front) the individual injuries were known (Figure 8). As far as the frequency is concerned the head injuries dominate (61.2%), followed by injuries to the arms (20.9%) and the legs (16.4%).

The serious AIS 2-6 injuries were mainly restricted to the parts of the body head, shoulder, arms, abdomen and legs. The injury descriptions (AIS 2-6) can be seen in Figure 8 below.

The 67 injured, unrestrained children in head-on collisions sustained a total of 93 individual injuries, so that the average number of individual injuries was thus 1.39 per injured child.

**Side collisions**. In the case of a side impact, too, (Figure 9) the head injuries (55.6%) dominated among the unrestrained children (a total 27 injured children); however, the second most frequent injuries were those to the legs (44.4%), and only then do the arms follow with an injury frequency of 37.0%.

The individual AIS 2-6 injuries were observed to the head, abdomen and legs; they are set out in Figure 9 below.

The 27 injured, unrestrained children in side collisions sustained a total of 45 individual injuries. The average number of individual injuries were thus 1.67 for each child injured.

**Rear-end collisions**. In rear-end collisions altogether 21 unrestrained children were injured; again it was the head (42.8%) which was effected most frequently. However, neck injuries, which make up 14.3% (all AIS 1), followed in second place, the same injury frequency (14.3%) arising for the arms.

In rear-end collisions altogether two serious AIS 2-6 injuries were recorded: a skull fracture and an upper arm fracture.

The total of individual injuries amounted to 23, and the average number of individual injuries was thus 1.10 in the case of the 21 injured, unrestrained children in rear-end collisions.
Unrestrained children
0 – 12 years

Impact area front

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<tr>
<th>AIS 1</th>
<th>AIS 2</th>
<th>AIS 3-5</th>
<th>AIS 6</th>
<th>Rel. prop. of injuries</th>
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<td>--</td>
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<td>Chest</td>
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<td>--</td>
<td>--</td>
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<tr>
<td>Arms</td>
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<td>1</td>
<td>2</td>
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<td>--</td>
<td>2</td>
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<td>Legs</td>
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<td>Bruises/Abrasions</td>
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</table>

Injury description for AIS 2-6

**Head**
- AIS 2: Forehead bruised
- Cuts
- Haematoma
- Light concussion (2)
- Severe concussion (4)

**AIS 3:** Severe concussion
- Skull fracture

**Shoulder**
- AIS 2: Collarbone fracture

**Arms**
- AIS 2: Upper arm fracture (2)
- Finger amputation

**Abdomen/Pelvis**
- AIS 6: Liver lesion

**Legs**
- AIS 2: Thigh fracture
- Lower leg fracture (2)

Number in ( ) = No. of injuries

Figure 8. Frequency and severity of injuries to various parts of the body in unrestrained children in head-on collisions; description of serious and fatal AIS 2-6 injuries
Unrestrained children
0 – 12 years

Impact area side

<table>
<thead>
<tr>
<th></th>
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<th>AIS 3-5</th>
<th>AIS 6</th>
<th>Rel.prop.of Injuries</th>
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<tr>
<td>Neck</td>
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<tr>
<td>Arms</td>
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<td>3.7%</td>
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Figure 9. Frequency and severity of injuries to various parts of the body in unrestrained children in side collisions; description of serious and fatal AIS 2-6 injuries
**Roll-over accidents**. Together 11 children were injured in 9 roll-over accidents; most frequent (54.5%) were bruises/abrasions to all parts of the body, and injuries to the head, the arms and the knees, each having a frequency of 18.2%. All injuries were below AIS 2. This fact is very surprising: through fortunate circumstances even very serious roll-over accidents accompanied by relatively severe damage to the vehicle can be withstood by children with slight injuries, even though they are unrestrained; but the risk cannot be calculated. The average number of individual injuries was 1.18 in the case of the 11 injured, unrestrained children in roll-over accidents.

**Injury patterns of unrestrained children**

A summary of the individual injuries for all impact areas including roll-over is presented in Figure 10. If the three most frequent individual injuries are arranged in order the following list of priorities results for unrestrained children:

1. head injuries (55.4%),
2. injuries to the arms (21.6%) and to the legs (21.0%),
3. bruises and abrasions on all parts of the body (14.9%).

The AIS 2-6 injuries are again summarised and presented in Figure 10 below.

The average number of individual injuries was 1.38 in the case of all of the 148 injured unrestrained children.
Unrestrained children
0 – 12 years

All impact areas

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<th>AIS 3-5</th>
<th>AIS 6</th>
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<td>14.9%</td>
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</table>

Injury description for AIS 2-6

**Head**
- AIS 2: Forehead bruised
  - Cuts
  - Haematoma (2)
  - Eyelid torn off
  - Yokebone fracture
  - Skull fracture
  - light concussion (5)
  - severe concussion (5)
- AIS 3: severe concussion (3)
- AIS 4: severe skull/brain trauma
  - Hemiplegia

**Shoulder**
- AIS 2: Collarbone fracture

**Arms**
- AIS 2: Upper arm fracture (3)
  - Lower arm fracture complete
  - Finger amputation

**Abdomen/ Pelvis**
- AIS 2: Pelvic fracture
- AIS 4: Kidney lesion
- AIS 6: Liver lesion

**Legs**
- AIS 2: Thigh fracture (4)
  - Fracture of neck of femur
  - Lower leg fracture (3)

Number in ( ) = No. of injuries

Figure 10. Frequency and severity of injuries to various parts of the body in unrestrained children, all collision types; description of serious and fatal AIS 2-6 injuries

- 15 -

Langwieder
Restrained children (n = 865)

Age distribution

The age distribution of the restrained children is shown in Figure 11. The group of 1-year-olds with 185 children is most frequently affected, followed by the group of 2-4-year-olds and those below one year; the older children make up a relatively small proportion.

Age and sitting position

The sitting position of the restrained children is shown in Figure 12: 14 children (1.6%) were sitting on the front right-hand seat, 412 (47.7%) on the rear right-hand seat, 190 (22.0%) in the middle of the rear seat and 248 (28.7%) on the rear left-hand seat.

The age distributions in the 3 sitting positions at the rear resemble each other very strongly, although it is noticeable that a slightly higher proportion of the older children were sitting behind on the left.

Figure 11. Age distribution of restrained children in cars
Figure 12. Sitting position and age of restrained children in cars
Distribution of the injury severity and age

The distribution of the injury severity MAIS for all 865 restrained children is shown in Figure 13: 715 children (82.7%) remained uninjured, 150 children (17.3%) sustained MAIS 1-6 injuries. The proportion of the injury severity MAIS 2-6 was only 1.4%.

Dependent on age it can be seen that all MAIS 3-6 injuries were sustained only by children aged from 0-2 years; the severest injuries to children aged 3 or above in the study material were MAIS 2.

Distribution of injury severity and collision type

The maximum injury severity (MAIS) dependent on the collision type was known for 811 children.

An important finding is that in both rear-end collisions and roll-over accidents no child sustained injuries above MAIS 2, with the exception of one child which was thrown out of

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<td>6</td>
</tr>
<tr>
<td>Total %</td>
<td>715</td>
<td>137</td>
<td>8</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>865</td>
</tr>
<tr>
<td></td>
<td>82.7</td>
<td>15.9</td>
<td>0.9</td>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Figure 13. Distribution of the injury severity MAIS and of the age of restrained children in cars

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Langwieder
the child restraint system and out of the car in an roll-over accident and was fatally injured. The serious or critical and fatal injuries only occurred in head-on or side collisions, but their frequency is very slight.

Individual injuries to the various parts of the body

**Head-on collisions.** In the case of 77 injured, restrained children in head-on collisions, the individual injuries were known (Figure 14). As far as the frequency is concerned it is

### Restrained children
0 – 12 years

**Impact area front**

<table>
<thead>
<tr>
<th></th>
<th>AIS 1</th>
<th>AIS 2</th>
<th>AIS 3-5</th>
<th>AIS 6</th>
<th>Rel.prop.of injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Head</strong></td>
<td>48</td>
<td>2</td>
<td>--</td>
<td>--</td>
<td>64.9%</td>
</tr>
<tr>
<td><strong>Neck</strong></td>
<td>5</td>
<td>--</td>
<td>1</td>
<td>--</td>
<td>7.8%</td>
</tr>
<tr>
<td><strong>Shoulder</strong></td>
<td>5</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>6.5%</td>
</tr>
<tr>
<td><strong>Chest</strong></td>
<td>10</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>12.9%</td>
</tr>
<tr>
<td><strong>Arms</strong></td>
<td>4</td>
<td>2</td>
<td>--</td>
<td>--</td>
<td>7.8%</td>
</tr>
<tr>
<td><strong>Abdomen/Pelvis</strong></td>
<td>10</td>
<td>1</td>
<td>--</td>
<td>1</td>
<td>15.6%</td>
</tr>
<tr>
<td><strong>Legs</strong></td>
<td>6</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>7.8%</td>
</tr>
<tr>
<td><strong>Bruises/Abrasions</strong></td>
<td>3</td>
<td>--</td>
<td></td>
<td></td>
<td>3.9%</td>
</tr>
</tbody>
</table>

**Injury description for AIS 2-6**

- **Head**
  - AIS 2: - light concussion
    - severe concussion

- **Neck**
  - AIS 5: - Tetraplegia

- **Arms**
  - AIS 2: - Closed fracture

- **Abdomen/Pelvis**
  - AIS 2: - Bruised kidney
  - AIS 6: - Liver lesion

Figure 14. Frequency and severity of injuries to various parts of the body in restrained children in head-on collisions; description of serious and fatal AIS 2-6 injuries
the head injuries (64.9%) which are strongly dominant, followed by abdominal injuries (15.6%) and chest injuries (12.9%). Whereas the chest injuries were all AIS 1 bruises, the abdominal injuries were relatively serious or fatal.

There were relatively few AIS 2-6 injuries; they were distributed to the head, neck, arms and abdomen. A description of the AIS 2-6 injuries is to be found in Figure 14 below.

The 77 injured, restrained children in head-on collisions sustained a total of 98 individual injuries, the average number of individual injuries thus amounting to 1.27 per injured child.

**Side collisions** In the case of side impacts (Figure 15) the head injuries (58.3%) dominated in the restrained children (altogether 24 injured children); here injuries to the neck are the second most frequent (25.0%), only then do the arms and the shoulder follow with an injury frequency of 16.7% in each case.

The serious AIS 2-6 individual injuries were concentrated on the head, neck, shoulder, chest, arms and abdomen. These serious AIS 2-6 injuries are described in Figure 15 below.

The 24 injured, restrained children in side collisions sustained a total of 36 individual injuries, and the average number of individual injuries was thus 1.50 per injured child.

**Rear-end collisions** In the case of altogether 25 injured, restrained children it was the head that was injured most frequently (44.0%) in rear-end collisions as well. Then followed neck injuries (36.0%) and injuries to the arms and the abdomen (16.0% in each case). All the 35 individual injuries observed were, however, AIS 1 injuries.

The average number of individual injuries was 1.40 for the 25 injured, restrained children in rear-end collisions.

**Roll-over accidents** In 9 roll-over accidents only 3 restrained children were injured. All 3 sustained head injuries, two being slight AIS 1 injuries and one a serious AIS 6 skull and brain trauma; this accident has already been mentioned above: the child was thrown out of the child’s seat and the vehicle and killed.
Restraint children
0 – 12 years

Impact area side

<table>
<thead>
<tr>
<th></th>
<th>AIS 1</th>
<th>AIS 2</th>
<th>AIS 3-5</th>
<th>AIS 6</th>
<th>Rel.prop.of injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>10</td>
<td>2</td>
<td>2</td>
<td>--</td>
<td>58.3%</td>
</tr>
<tr>
<td>Neck</td>
<td>5</td>
<td>--</td>
<td>1</td>
<td>--</td>
<td>25.0%</td>
</tr>
<tr>
<td>Shoulder</td>
<td>2</td>
<td>2</td>
<td>--</td>
<td>--</td>
<td>16.7%</td>
</tr>
<tr>
<td>Chest</td>
<td>1</td>
<td>1</td>
<td>--</td>
<td>--</td>
<td>8.3%</td>
</tr>
<tr>
<td>Arms</td>
<td>4</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>16.7%</td>
</tr>
<tr>
<td>Abdomen/ Pelvis</td>
<td>1</td>
<td>1</td>
<td>--</td>
<td>1</td>
<td>12.5%</td>
</tr>
<tr>
<td>Legs</td>
<td>2</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>8.3%</td>
</tr>
<tr>
<td>Bruises/ Abrasions</td>
<td>1</td>
<td>--</td>
<td></td>
<td></td>
<td>4.2%</td>
</tr>
</tbody>
</table>

**Injury description for AIS 2-6**

- **Head**
  - AIS 2: Laceration
  - AIS 3: Severe skull/brain trauma
  - AIS 5: Severe skull/brain trauma

- **Neck**
  - AIS 5: Tetraplegia

- **Shoulder**
  - AIS 2: Fracture
  - Collarbone fracture

- **Chest**
  - AIS 2: Fractured ribs

- **Arms**
  - AIS 2: Closed fracture

- **Abdomen/ Pelvis**
  - AIS 2: Blunt abdominal trauma
  - AIS 4: Kidney lesion

Figure 15. Frequency and severity of injuries to various parts of the body in restrained children in side collisions; description of serious and fatal AIS 2-6 injuries
Injury patterns of restrained children

A summary of the individual injuries for all impact areas including roll-over is presented in Figure 16. If the three most frequent individual injuries are ranged in order the following list of priorities results for restrained children:

1. head injuries (60.4%),
2. neck injuries (15.3%),
3. abdominal injuries (13.9%).

The injuries to these three parts of the body dominate; however, not only as far as frequency is concerned but also with regard to the severity of the injuries; AIS 3-6 injuries were observed not only to the head and neck but also to the abdomen. The AIS 2-6 injuries are again summarized and described in Figure 16 below. The average number of individual injuries to the altogether 144 injured, restrained children was 1.30.

The use of different restraint systems

The ECE-regulation No. 44 /7/ defines four weight classes for children’s restraint systems:

Class 0: below 10 kg
Class I: 9 to 18 kg
Class II: 15 to 25 kg
Class III: 22 to 36 kg

Five different child restraint systems (similar systems were combined) in the Groups I and II/III were examined to establish to what extent these weight ranges are observed in reality. The Weight Class 0 contained only a few individual cases, so that here they could not be taken into account.

Weight Class I:
System 1: seat plus arresting device (e.g. Römer Peggy)
Restrained children
0 – 12 years
All impact areas

<table>
<thead>
<tr>
<th>AIS 1</th>
<th>AIS 2</th>
<th>AIS 3–5</th>
<th>AIS 6</th>
<th>Rel.prop.of injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>80</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Neck</td>
<td>20</td>
<td>--</td>
<td>2</td>
<td>--</td>
</tr>
<tr>
<td>Shoulder</td>
<td>12</td>
<td>2</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Chest</td>
<td>13</td>
<td>1</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Arms</td>
<td>13</td>
<td>2</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Abdomen/Pelvis</td>
<td>18</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Legs</td>
<td>11</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Bruises/Abrasions</td>
<td>4</td>
<td>--</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Injury description for AIS 2–6**

- **Head**
  - AIS 2: - Laceration
  - light concussion (2)
  - severe concussion (2)
  - AIS 3: - severe skull/brain trauma
  - AIS 5: - severe skull/brain trauma
  - AIS 6: - severe skull/brain trauma

- **Neck**
  - AIS 5: - Tetraplegia (2)

- **Shoulder**
  - AIS 2: - Fracture
  - Collarbone fracture

- **Chest**
  - AIS 2: - Fractured ribs

- **Arms**
  - AIS 2: - Closed fracture (2)

- **Abdomen/Pelvis**
  - AIS 2: - Blunt abdominal trauma
  - Bruised kidney
  - AIS 4: - Kidney lesion
  - AIS 6: - Liver lesion

**Number in ( ) = No. of injuries**

Figure 16. Frequency and severity of injuries to various parts of the body in restrained children, all collision types; description of serious and fatal AIS 2-6 injuries.
System 2: seat plus adult’s 3-point-belt (e.g. Sicartex Kiddy)
System 3: adjustable seat with integrated 4-point belt system (e.g. Storchenmühle Prestige, International Luxus).

Weight Class II:
System 4: arresting device (e.g. Römer Varlo)

Weight Class II/III:
System 5: padded seat/cushion (e.g. Autoflug Toppy)

Altogether 277 children were restrained by System 1, and 245 of these (88.4%) were in the correct weight range between 9 kg and 18 kg. 21 children (7.6%) weighed 19 kg or more, and 11 children (4.0%) 8 kg or less.

Altogether 58 children were restrained by System 2. These children were in the weight range between 8 kg and 20 kg; after this system was tested for the Weight Class I and Class II according to the ECE all the children (with the exception of 2 children weighing 8 kg) were in the admissible weight range.

Altogether 140 children were restrained by System 3; 4 (2.9%) were too heavy and 13 (9.3%) too light. Two of the children who were too heavy weighed 30 kg each (the system is tested up to 18 kg).

Altogether 102 children were restrained by System 4, approved for 15 to 25 kg, only 71 (69.6%) being in this admissible weight range. 15 children (14.7%) were too heavy, and 16 children (15.7%) too light. Here, too, - as in the case of System 3 - it could again be observed that the admissible weight was in some cases quite considerably exceeded; thus here, in two cases, the weight was 35 kg, in one case 40 kg, and in another 44 kg.

Altogether 51 children were restrained by System 5; 45 (88.2%) of these weighed over 15 kg and were thus in the admissible weight range. But as this system uses padded seats, its correct use is less a question of weight than of the child’s height. When using it special attention has to be paid to see that the shoulder belt does not lie too close to the neck.

Not only were the five different child restraint systems in the Weight Classes I and II/III examined, but investigations were also conducted into the height of those children restrained solely by a 3-point belt for adults. The available accident material contained
altogether 63 children restrained by 3-point belts, the ages ranging from 1 to 12 years and the height from 90 cm to 150 cm. The latest research shows that a 3-point belt can be worn by a child with a height of 120 to 140 cm; which limit applies depends, on the one hand, on the height of the seated child himself and, on the other, on the height of the upper anchorage point of the rear-seat belt.

In the available accident material altogether 20 children (31.7%) were smaller than 120 cm, and 39 children (61.9%) were smaller than 140 cm. Depending on whether the limit of 120 cm or 140 cm assumed, it thus emerges that between one-third and two-thirds of all children who were restrained by 3-point belts only were still too small for the use of 3-point belts alone.

DISCUSSION OF THE MAIN FINDINGS

Sitting position

A comparison of the sitting positions of unrestrained and restrained children (Figure 6 and Figure 12) revealed above all three essential differences: firstly, the proportion of unrestrained children sitting on the "front right-hand" seat was greater than among the restrained ones; secondly, the position "rear-centre" was more frequently occupied in the case of the unrestrained children; and, thirdly, the restrained children were sitting far more frequently on the "right-hand rear" seat.

The sitting position on the "left-hand rear" seat had the same relative frequency of 27-29% in the case of the unrestrained and restrained children.

Distribution of the injury severity

Figures 7 and 13 show the MAIS distributions for unrestrained and restrained children; a comparison shows that far more of the restrained children remained uninjured (82.7% compared with 48.6% in the case of the unrestrained children).

If the serious to fatal injuries (MAIS 3-6) are combined, this results in a relative proportion of only 0.5% of the restrained children; but for the unrestrained children there is a relative proportion of 3.5%. In the accident material considered here the risk of serious/fatal injuries for the unrestrained children is seven-times higher than for the restrained ones. If the proportion of fatal injuries (MAIS 6) is compared it emerges that the unrestrained
children are exposed to a risk of fatal injuries which is 3.5-times higher than for the restrained ones.

The MAIS distribution depending on age (Figure 7 and Figure 13) illustrates that among the restrained children only those aged from 0 to 2 years sustained MAIS 3-6 injuries, while among the unrestrained children the MAIS 3-6 injuries were distributed over all age-groups. Here the question arises as to whether the child restraint systems on sale and used in Germany today could not be even further improved for the age-group 0-2 years; at any rate, more attention will have to be paid to this age-group in the future.

The distribution of the injury severity depending on the type of collision has shown that - both for unrestrained and restrained children - the serious/fatal injuries primarily occur in head-on and side collisions, but that very serious/fatal injuries may also arise in roll-over accidents.

**Injuries to the different parts of the body**

The frequency and severity of individual injuries to the different parts of the body, depending on the type of collision, have already been described in detail. The most important finding here was that there are completely different injury patterns for unrestrained and restrained children: in the case of unrestrained children the injuries are concentrated on the head, the arms and legs; in the case of restrained children they are concentrated on the head, the neck and the abdomen. Although the head is most frequently injured in the case of restrained and also unrestrained children, the proportion of serious head injuries (AIS 2-6) to unrestrained children was 7.3 times higher than to restrained children (288 unrestrained children with 17 AIS 2-6 head injuries; 865 restrained children with 7 AIS 2-6 head injuries). That it is the neck that is most frequently injured among the restrained children is mainly due to the fact that many slight neck injuries (AIS 1) occurred, although there were also 2 AIS 5 neck injuries (one in a head-on collision of medium accident severity and one in an extremely serious side collision).

Injuries to the abdomen ranked third in the frequency distribution for the restrained children; here the same applies as for the neck injuries: the proportion of slight abdominal AIS 1 injuries is very high, but there are also a few serious/fatal injuries (AIS 2-6). This proportion of serious/fatal abdominal injuries (AIS 2-6) is, however, considerably lower in the case of the restrained children than the unrestrained ones (865
restrained children with 4 abdominal AIS 2-6 injuries; 288 unrestrained children also with 4 abdominal AIS 2-6 injuries).

One main point of injury which had turned out to be dominant among the unrestrained children - injuries to the arms and legs - hardly appeared at all among the restrained children: with the exception of two upper arm fractures, only AIS 0/1 injuries to the arms and legs were observed among all the other restrained children.

In the case of the restrained children the analysis of the individual injuries revealed that a relatively large proportion of serious AIS 2-6 injuries occurs in side collisions (compare Figure 14 and Figure 15) and in future more attention should be paid to this kind of loading.

The risk of neck injuries

In the accident material for this study there is one case in which a child aged 10 months sustained a neck injury in a head-on collision which resulted in tetraplegia even though it was restrained in a child’s seat with a 4-point belt. The accident severity was an EES /8/ of about 35-40 kph.

On account of this individual case the HUK-Verband carried out extensive research in Germany with regard to these neck injuries, and two more cases were found in which children sustained a neck fracture; in one case the injury was fatal, and in the other it resulted in tetraplegia. The cases show agreement insofar as they were head-on collisions with an accident intensity of below EES = 50 kph, the systems restraining the children had 4-point belts and the children were in the 9-12-month age-group. It is noticeable that all neck injuries that have so far come to light have a severity of either AIS 1 or AIS 5/6; the AIS 2-4 range hardly ever seems to occur in the case of infants who sustain neck injuries.

It is still not possible to understand and objectify the mechanisms and causes of serious neck injuries, especially against the background of the obviously many cases of equal or greater accident severity in which children remain uninjured in restraint systems with 4-point belts.

At least seen from our present standpoint, it seems certain that the occurrence of critical neck injuries is primarily not a problem of the accident severity, but a problem of unfortunate circumstances coinciding.
It is not known today how frequently neck fractures occur, but the fact that such cases actually do arise in practice must not be ignored. On the other hand, they should not be overestimated, either, since the cases to date - as research has shown - occurred spread over several years, and further cases do not seem to be known in Germany at present. Moreover, nor should those children be excluded from consideration who - because they were using a child restraint system - were spared serious or fatal injuries, for example fatal head injuries.

SUMMARY

Each year in Germany about 100 children are killed and some 11,500 are injured as passengers in cars. The overall rate of children using a restraint system amounts at present to only 50-60%, and is thus far too low.

By 1988 the Accident Research Division of the HUK-Verband had collected from a total of about 3,500 car accidents information on 437 children, of whom 135 were restrained and 302 were not.
It proved difficult in the necessarily short time using conventional methods to build up accident material which made it possible not only to obtain information on the children's injury criteria but also effective analyses of the different restraint systems.

As part of a campaign run jointly by the HUK-Verband and a major German newspaper in 1988, new accident material was built up which today comprises 870 car accidents with 1,153 children (288 unrestrained and 865 restrained) aged between 0 and 12 years. Most of the accidents were car/car accidents (65-75%), followed by single car accidents (15-20%) and collisions between a car and a truck or a bus (5-10%).
50-60% of the accidents were head-on collisions, 20-25% were side collisions, the left-hand side of the car being struck more frequently.

In the case of the unrestrained children the injuries were concentrated on the head (about 55%) and the arms and legs (21% each). Serious AIS 3-6 injuries occurred mainly to the head and abdomen.

Injury concentrations according to age groups could not be observed in the unrestrained children, and serious/fatal injuries were distributed over all the age-groups.
In the case of the restrained children the serious injuries were concentrated chiefly among the children aged 0 to 2 years. Although at present this observation cannot be explained, it can be inferred from it that more attention should be paid to the protective effect of restraint systems particularly in the case of infants, and there seems to be a need for improvement here.

Children using restraint systems also sustain head injuries most frequently, but usually AIS 1 injuries. The protective effect of these systems clearly emerges in a reduction of the injury severity: the proportion of serious head injuries was about seven times higher in the case of the unrestrained children.

Injuries to restrained children are also concentrated on the neck and abdomen. Although the neck injuries were mostly slight (AIS 1), individual cases of neck fractures were also observed; this statement applies correspondingly to the abdominal injuries with mostly slight injuries (AIS 1), but some of these were very serious. The proportion of abdominal injuries is, however, about three times higher in the unrestrained than the restrained children.

Severe injuries to the arms and legs - such as were observed in the unrestrained children - hardly occurred at all in the case of the restrained children.

It was head-on and side collisions which resulted in the most serious injuries. It emerged that the side accident is very significant compared with the head-on collision: the number of serious AIS 3-6 injuries in the study material was even twice as high as in head-on collisions. For this reason, in future more attention should be paid to the loading which occurs to restrained children in side accidents.

An examination of the extent to which the weight classes defined in ECE-R 44 were observed in reality showed that 90-95% of the children restrained by means of the systems in Class I were neither above or below the permitted range; in individual cases, however, the body weight was definitely too high. Only 70% of the children in systems in Class II were within the permissible weight range, 15% of the children were too light and 15% too heavy; the weight was sometimes exceeded quite considerably.

For this reason it should be pointed out to parents more emphatically than hitherto that they must observe the weight limits given by the manufacturers of children’s seats, so that the protection potential is not reduced.

With regard to the use of 3-point belts it could be seen that one- to two-thirds of all children restrained in this way were too small.
Although the available material only made it possible to compare the tendency of restrained and unrestrained children, the beneficial effect of child protective systems was confirmed.

In isolated cases, however, an injury pattern that it had not been possible to notice previously showed up in the case of restrained children aged from 9-12 months, namely serious neck injuries. Although these injuries seem to be extremely rare, they do occur and must not be ignored.

The biomechanical research into the limits of loading that can be endured by children, especially infants up to the age of 18 months, must be intensified. Precisely because these studies can only produce reliable results on a long-term basis, this work should be begun as soon as possible.

Rearward-facing systems, as far as possible with defined, integrated installation in the car, should be offered for sale in larger numbers, especially for infants up to the age of 18 months.

New measuring methods, which make it possible to assess the motion sequences and the loading in the spinal region, must be developed and integrated in the test requirements of ECE-R 44.

The weight range covered by Group I of ECE-R 44 of between 9 and 18 kg relates to the age groups of children with completely different injury risks. Dividing this group up or modifying the individual criteria between Group 0/1 should ensure that more consideration is given to the special biomechanical accident characteristics of children between 9 and 18 months.

For this purpose, infant dummies of 9 and 18 months should exist to make it possible to carry out realistic measurements of the loading on the neck and abdomen.

In the ECE tests more attention should be paid to protective criteria in side collisions, but more precise experience from accident research will have to be made available.

Intensified international cooperation must create a wider basis, so that experience of biomechanical criteria can also be obtained in the case of rare but dangerous accident circumstances together with system-related knowledge on the safety effect achieved by child protective systems.
ACKNOWLEDGEMENTS

The German Motor Vehicle Insurers owe a debt of gratitude to the newspapers AutoBild and Bild for their support of the public campaign which made this new direct sampling method possible and resulted in the accident material described. Special thanks are due to Mr. Peter J. Glodschey, Editor-in-Chief, and Mr. Joachim R. Walther for their personal commitment and support.

The authors would also like to thank Messrs. Fritz Finkbeiner and Hans-Dieter Zipfel, research engineers, for carrying out the accident analysis and the evaluation work, Mr. Helmut Klein, Dipl.-Ing., for programming and handling the special data base, and Mr. Geoffrey P. Burwell of the Sprachen- und Dolmetscher-Institut, Munich, for the translation of the study.
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