INJURY RISKS, MISUSE RATES AND THE EFFECT OF MISUSE DEPENDING ON THE KIND OF CHILD RESTRAINT SYSTEM

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1 ABSTRACT

The compulsory use of child restraint systems (CRS) in cars which came into force on 1st April 1993 led to a considerable increase in the belting rate of children in Germany, but between 30% and nearly 60% of the children aged 0<12 years are only restrained by an adult belt (lap or three-point belt).

On the basis of a new accident material of the German Motor Insurers (593 restrained children 0 to 12 years involved in 448 car accidents) the injury risk of children being belted with an adult belt only is compared to those injury risks of children being restrained in different types of CRS (4/5-point belt, 3-point belt, impact shield, booster cushion). The form of restraint "child with an adult belt only" involves disproportionately high risks.

In retrospective accident studies it is relatively difficult to get detailed information about the frequency and the exact kind of CRS misuse. Therefore 250 users of CRS were observed and interviewed. Only in one third of these observations the CRS were correctly mounted; depending on different types of CRS the misuse rates lay between 20 and 90%.

To check up the effect of the most frequent and most severe kinds of misuse 20 crash tests with wrong fitted CRS were carried out; for this reason tests with an ECE sled and with a cut-off car body have been performed. Depending on the kind of CRS a partly considerable reduction of the safety effect of CRS could be observed in case of misuse. Protection against misuse by a proper design has to be given highest priority for the safety improvement of future CRS.

2 INTRODUCTION

The number of children killed in car accidents in West Germany [18] has been reduced significantly during the past 25 years (Fig. 1). In view of the total number of children killed in traffic accidents, however, fatalities involving children in automobile accidents continue to rank first compared with children in pedestrian or bicycle accidents.

A comparison of individual countries indicates that children in Middle Europe and Canada (Table 1) are relatively frequently restrained when travelling in automobiles.

Table 1: International comparison of securing quota of children in cars

<table>
<thead>
<tr>
<th>Country</th>
<th>Year</th>
<th>Age</th>
<th>Quota</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>94</td>
<td>up to 12 yrs.</td>
<td>87%</td>
</tr>
<tr>
<td>Sweden</td>
<td>94</td>
<td>up to 15 yrs.</td>
<td>87%</td>
</tr>
<tr>
<td>France</td>
<td>91-62</td>
<td>up to 12 yrs.</td>
<td>61%</td>
</tr>
<tr>
<td>Canada</td>
<td>92*</td>
<td>up to 9 yrs.</td>
<td>73%</td>
</tr>
</tbody>
</table>

* Inref City

Source: Federal Statistical Office of Germany

Figure 1: Children (from 0 to 14 years of age) killed in car accidents in West Germany
Annual surveys conducted by the Federal German Highway Research Institute (BASt) [1], however, confirmed that children are often restrained on an irregular basis with adult seat belts only. This led German legislators to introduce in April 1993 a statutory obligation for the mandatory use of child restraint systems (CRS) in automobiles. It is stated in this law that children who have not yet completed the age of 12 and are shorter than 150 cm may only ride in automobiles if secured in child restraint systems that are suitable for children and have official approval. This measure resulted in a significant increase in the percentage of children being restrained while travelling in cars (1992 = 72%; 1996 = 88%) and also led to a drop in the number of children killed in car accidents (28% decrease from 1992 to 1996).

A more detailed analysis of the percentage of children restrained in cars (Fig. 2) shows that children up to the age of five years are usually placed in child protection systems and that only a few are restrained using an adult seat belt and "only" 8% travel without any kind of protection. In the case of children between the ages of six and eleven years, on the other hand, only 27% use a special child protection system, 50% use an adult seat belt and almost one out of every four children in this age group does not use any kind of safety protection.

In order to obtain additional information about the risk of injury as a function of the type of restraint system in real accident situations, new statistical accident data based exclusively on restrained children was set up and analysed within the scope of a research project entitled "Improving the Protection of Children in Automobiles" [7]. In addition, parents were observed and interviewed as to how they secure their children in cars and whether or not they make mistakes (misuse in the sense of "incorrect installation of the child protection system" and "improper restraint of children in restraint devices"). The most frequent or most serious types of misuse were reproduced in sled tests. A field study was devoted to determine whether or not mistakes made during installation of a child restraint system can be avoided by using ISOFIX, a standardised rigid snap-type connection for mounting child protection systems [8].

3 RESULTS OF REAL ACCIDENT ANALYSIS

3.1 STATISTICAL DATA

All automobile accidents involving at least one restrained child less than 12 years of age were retrieved from the "Vehicle Safety 90" accident data [9]. This created a new accident database entitled "Child Safety 90" and included 448 car accidents with details about 593 restrained children between 0 to 12 years of age. This new accident material was based on approximately 18,000 car accidents involving personal injury in the period 1990 and 1991.

3.2 AGE DISTRIBUTION

The relatively well-balanced age distribution that exists (Fig. 3) indicates the great importance of child restraint for all age groups, since even the numerically smallest age group (6 years) had an incidence of N = 35 in the statistical data.

![Figure 2: Percentage of children restrained in cars according to age groups (Germany, city traffic, 1996)](image)

![Figure 3: Age distribution (N = 593 restrained children)](image)
3.3 DISTRIBUTION OF IMPACT AREAS

A comparison of different accident databases at the Institute for Vehicle Safety reveals that the statistical data contained in the "Child Safety 90" database relates to accidents with a relatively high extent of vehicle damage and relatively serious accidents.

Head-on collisions occurred in 340 cases (57%) and were thus around three times more frequent than side collisions (120 cases, 20%) or rear-end collisions (126 cases, 21%). Rollover accidents were observed in only 7 cases.

However, if the maximum abbreviated injury scale (MAIS) [10] is included in these considerations, a totally different picture emerges (Fig. 4). In the case of front-end collisions, only 16% of the restrained children suffered MAIS 2+ injuries compared with 26% of those involved in side collisions. The risk to children on the struck side of the vehicle is particularly high.

In order to reduce the high risk to such children, child restraint systems should in the future be subjected to the most realistic possible side collision tests and be further improved by incorporating appropriate design measures. International work is currently in progress on a suitable inspection and test protocol [11,12].

The consequences of injury sustained during rear-end collisions and rollover accidents were comparatively noncritical in this case material (refer to Fig. 4), since MAIS 2 injuries were the most serious degree of injury observed in these accidents.

![Figure 4: Frequency of MAIS 2+ injuries as a function of the impact area (N = 92)](image)

3.4 SEVERITY OF INJURY AS A FUNCTION OF THE TYPE OF RESTRAINT

An analysis of the severity of injury as a function of the type of restraint (Table 2) shows that children who were restrained in child protection systems were injured much less frequently (42%) than children restrained with a lap belt or three-point belt (13%). The range of moderate to fatal injuries shows clearly (see Table 2) that a frequency of MAIS 2+ injuries to children in a child protection system (11%) is less than to children restrained by three-point/lap belts (26%). It is clearly obvious that there is a trend to a greater severity of injury in children who were restrained with an adult seat belt only. These trends are also confirmed by an analysis of the frequency of injury to different body parts and the frequency of incidence of multiple injuries.

Table 2: MAIS distribution as a function of the type of restraint

<table>
<thead>
<tr>
<th></th>
<th>CRS</th>
<th>3-point belt/ lap belt</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>%</td>
</tr>
<tr>
<td>MAIS 0</td>
<td>83</td>
<td>41.5</td>
</tr>
<tr>
<td>MAIS 1</td>
<td>95</td>
<td>47.5</td>
</tr>
<tr>
<td>MAIS 2</td>
<td>17</td>
<td>8.5</td>
</tr>
<tr>
<td>MAIS 3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MAIS 4/5</td>
<td>2</td>
<td>1.0</td>
</tr>
<tr>
<td>MAIS 6</td>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td>total</td>
<td>200</td>
<td>100</td>
</tr>
</tbody>
</table>

3.5 THE SAFETY PROTECTION AFFORDED BY VARIOUS CHILD RESTRAINT SYSTEMS

Yet another phase of assessment dealt with questions about any conspicuous features observed in the use of different types of child protection systems as far as the risk of injury and safety were concerned. The exact type of child protection system involved in the accident was known in a total of 120 cases (ECE-Group 0-II, defined in APPENDIX C). In order to obtain statistically significant results, this comparison investigated only head-on collisions that involved relatively severe injury (without disastrous intrusion; degree of damage 3+4, defined in APPENDIX A). Distinct differences were found between the individual types of child protection systems. Table 3 shows a great degree of safety in the ECE-Group I, particularly when the child is restrained with an impact shield system (no MAIS 2+ injuries). Children sustain fewest injuries (50%) with this type of child seat. There is a significantly higher tendency to severe injuries when 4/5-point systems (harness belts) are used. There were MAIS 2 injuries in four out of 20 cases: head injuries (concussions, lacerations, gashes) in two cases and leg injuries (tibia fractures) in another two cases. There are different reasons for these injuries: Pushing front seats too far back, rearwardly inclining flat backrests or placing a child seat in the sleeping position all serve to increase the
Table 3: MAIS distribution as a function of the type of child restraint system; only head-on collisions in serious accidents (degree of damage 3-4)

<table>
<thead>
<tr>
<th></th>
<th>rearward facing</th>
<th>4/6-point system</th>
<th>impact shield system</th>
<th>3-point system</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAIS 0</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>MAIS 1</td>
<td>2</td>
<td>12</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>MAIS 2</td>
<td>2</td>
<td>4</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>MAIS 3-6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>total</td>
<td>4</td>
<td>20</td>
<td>14</td>
<td>9</td>
</tr>
</tbody>
</table>

The MAIS distribution shows that children in both age groups who were restrained solely by a three-point seat belt were harmed much more frequently and suffered critical injuries more often. MAIS 2+ injuries were about three times more frequent when the child was restrained using only a three-point belt than when restrained with a three-point belt combined with booster cushion. The clear differences in the age groups ranging from 2 to 5 years are confirmation that one should avoid restraining a child with a three-point belt with or without booster cushions at too early an age. In view of these results, it can be recommended that even older children (from 6 to 11 years of age) should continue to use booster cushions.

4 OBSERVATIONS OF MISUSE

4.1 MATERIALS AND METHODS

As already mentioned, the introduction of a statutory obligation for the mandatory use of child restraint systems in Germany had an obvious impact on child safety in automobiles. As a result, the numbers of child protection systems actually in use has plainly increased. However, other deficits have emerged instead, as the statutory obligation did not have the same positive influence on the quality of child restraint use as it did on their quantity. Incorrect use of child seats leads to a marked reduction in the safety protection that is theoretically possible. Studies carried out in Europe on the quality of child restraint use [13] concluded that clearly more than half of all children are incorrectly restrained when travelling in cars. These realisations caused an observation and interview study to be set up within the scope of a research project entitled "Improvement in the Protection of Children in Automobiles" [7]. In order to be able to ascertain all aspects of misuse, technical and psychological aspects were combined in a holistic methodology. An observation protocol was drawn up based on the "Misuse Mode and Effects Analysis - MMEA" study [14] as well as on the basis of the observation forms developed by the ISO [15]. These were then extended and upgraded to a considerable extent for the purpose of this study. Information was collected that pertained to the vehicle and passengers, additional traits of the interviewed persons as well as detailed information about the children such as their age, sex, seating position, type of restraint and misuse. The interviews were conducted on the basis of a totally redesigned concept containing not only the particulars of the persons involved, the type of restraint, mounting and purchase of the child protection system, but also subjective assessments, judgements and expertise of the persons using the child protection systems.
4.2 THE RESULTS OF OBSERVATION

A random sampling containing a total of 250 observations/interviews provided information on 354 children under 12 years of age. All restraint systems that were representative of the German market (APPENDIX C) were taken into consideration within the scope of the study. Child protection systems belonging to ECE-Groups 0-III amounted to 83% the other children were restrained with the adult belt only.

Mistakes in installing the child seats or in securing the children in the seat were made in 63% of all children who were restrained using a child restraint system. As indicated by Figure 5, serious mistakes that could seriously impair the safety of the child were found in one-third of all cases.

![Figure 5: Misuse in the use of child restraint systems (N = 354)](image)

Depending on the kind of protection system, misuse rates were observed that ranged between 20% and in excess of 90% (Table 5). A comparison of 4- and 5-point systems illustrates that misuse can indeed be reduced by technical measures and further developments and in this case amounted to almost 25% at the very least. In addition to the misuse rate, the absolute number of mistakes made when installing the seat or restraining the child was of absolutely essential - in particular with a view to avoiding misuse - (see Table 5). It must be established that systems in which installing the seat and restraining the child are two separate operations (e.g. 4/5-point systems, rearward facing systems) exhibit a higher frequency of misuse than the other systems. The hitherto good results achieved using ECE-Group I impact shield systems were found to have a high misuse rate of 92% and were thus called into question. However, if one takes the frequency of mistakes into consideration, it will be found that this system is subject to only 1.3 mistakes per installation/restraint and thus has the most positive results except for ECE-Group II impact shield systems.

<table>
<thead>
<tr>
<th>System Type</th>
<th>Total</th>
<th>Misuse</th>
<th>Misuse Frequency per Installation/Securing</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECE-group 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rearward facing systems</td>
<td>18</td>
<td>10</td>
<td>55.6</td>
</tr>
<tr>
<td>ECE - group I</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-point system</td>
<td>63</td>
<td>57</td>
<td>90.5</td>
</tr>
<tr>
<td>5-point system</td>
<td>62</td>
<td>41</td>
<td>68.1</td>
</tr>
<tr>
<td>Impact shield system</td>
<td>13</td>
<td>12</td>
<td>92.3</td>
</tr>
<tr>
<td>ECE - group III</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-point system</td>
<td>24</td>
<td>6</td>
<td>25.0</td>
</tr>
<tr>
<td>ECE - group II</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impact shield system</td>
<td>5</td>
<td>1</td>
<td>.</td>
</tr>
<tr>
<td>ECE - group II/III</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Booster cushion</td>
<td>107</td>
<td>56</td>
<td>52.3</td>
</tr>
<tr>
<td>Total</td>
<td>292</td>
<td>183</td>
<td>62.7</td>
</tr>
</tbody>
</table>

The following serious forms of misuse were found for the individual types of systems:

- Seat belt guide not used
- Belt path incorrect (Picture 1)
- Seat installed in wrong direction
- Seat installed in wrong position
- Safety system not attached
- Weight limit exceeded
ECE-Group I; 4/5-point systems

- seat fastening loose (Picture 2)
- 4/5-point belt too loose (Picture 3)
- belt path incorrect (Picture 4)
- belt buckle positioned too high (Picture 5)
- seat attached incorrectly
- weight above or below weight limit
- seat defective/damaged
- seat installed in the wrong position
- parents used their own mounting construction
- 4-point shoulder belts passing beneath the arm
- 5-point shoulder belt hanging over the shoulder
- belt in the child seat unbuckled
- vehicle seat belt unbuckled

ECE-Group I; impact shield systems

- used without impact shield
- seat damaged
- impact shield used alone
- weight limit exceeded

ECE-Group I; 3-point systems

- used with lap seat belt

ECE-Group II/III; booster cushions

- shoulder belt passing beneath the arm (Picture 6)
- used with lap seat belt
- used too early, child still too small
- shoulder belt passing behind the back
4.3 RESULTS OF THE INTERVIEWS

The extent to which the person securing the child is convinced that the restraint system will enhance the child's safety is certainly important for the consistent and proper use of child seats. In response to the question whether the child seat currently being used provides adequate safety, 79% of the interviewees responded affirmatively, 18% of those interviewed were only partly convinced and in 5% of the cases, the person interviewed stated that (s)he was not generally convinced of the protection afforded by child seats. The reasons given for their mistrust were the inadequate mounting of the restraint system in the vehicle, the size of the child as well as the conviction that a child seat cannot prevent injury entirely.

The problem is that parents are often unaware that their child has not been properly restrained. Parents who had improperly restrained their child were asked: "Do you think that your child is properly restrained and that everything is OK?" In 60% of all cases, the response was "yes", i.e. they thought they had made no mistakes; only 21% of the respondents replied "no", indicating they were aware that a mistake had been made (Fig. 6).

![Question: "Do you think your child is properly restrained and that everything is OK?"

<table>
<thead>
<tr>
<th>Responses:</th>
</tr>
</thead>
<tbody>
<tr>
<td>yes</td>
</tr>
<tr>
<td>I think so</td>
</tr>
<tr>
<td>no</td>
</tr>
<tr>
<td>don't know</td>
</tr>
</tbody>
</table>

Figure 6: Interviews of parents who had improperly restrained their children

Asked to assess the possible consequences of incorrect or improper restraint measures, 20% of the respondents replied that they were in no position to judge the mistakes they had made as far as the safety of their child was concerned. 26% of the persons interviewed thought that incorrectly restraining the child would have no consequences whatsoever on the safety of the child. 32% of the respondents assumed that it might have a minor effect on or that it might slightly endanger the safety of the child, 20% thought there would be a considerable influence, and only 0.6% of those interviewed thought that the mistakes they had made in restraining their child would have a grave effect on or would gravely endanger their child's welfare.

5 MISUSE SLED TESTS

5.1 TEST METHODS

To determine what stress forces occur in situations in which children are improperly restrained or in which the restraint system is incorrectly installed, two series of sled tests were performed to simulate the most frequently observed and the gravest forms of misuse.

In the first series of tests (Picture 7), the child protection system was mounted on an ECE sled equipped with a rear seat bench from a VW Golf III.

In the second series of tests (Picture 8), the child protection systems were mounted in a cut-off car body mounted on a sled. Since it is impossible to detect all important risk factors that might cause considerable stress forces in a real accident, the sequence of events were also filmed using a high-speed camera. A total of 20 tests were carried out along the lines set forth in ECE-R 44 [16].

![Picture 7: Test series /1; ECE test sled](image)

![Picture 8: Test series /2; car body](image)
5.2 MISUSE SLED TEST RESULTS

The measurement data for all 20 test runs is set forth in Table 6.

ECE-Group 0 - (infant carrier) tests

Since all tests in ECE-Group 0 were performed using a "new-born" dummy which was not equipped with measuring sensors, the results can only be interpreted in this case with respect to forward displacement of head and motion analyses.

The results for tests 1 to 3 with different forms of "incorrect belt guide" reveal that in both test series the permissible corridor of 550 mm based on the point C₉₈ as defined in ECE-R 44 was exceeded but for one exception. A marked difference was shown in test 3/1 in which the seat disengaged completely from the seat attachment (Picture 9).

![Picture 9: Test 3/1; incorrect belt path]

When the restraint system is installed so that it faces forward (test 4), not only is there a danger that the forward displacement of the head will be exceeded, but there is also an additional risk that stress forces, which are likely to be very high, will be applied to the cervical vertebrae (Picture 10).

![Picture 10: Test 4/2; incorrect positioning of a rearward facing baby shell]

The film evaluation of the tests using the car body (second series of tests) clearly shows that in all ECE-Group 0 tests there is a danger of serious to fatal head injury when the head collides with the instrument panel or windshield.

ECE-Group 1 - (toddler seat) tests

Both series of tests illustrate differences in the measured forward displacement of the head. This is due to differences in the stiffness of the seats and in the geometry of the seat belt.

In test 5, a 5-point belt that was 25 mm too loose produced different results in both test series. In the first series (with the ECE sled), the acceleration to head and chest was higher, whereas in the second series (using the car body) a considerably higher forward displacement of the head was measured. It exceeded the limit of 550 mm by 88 mm and caused the legs of the test dummy to slam against the back of the front passenger seat. Both series of tests exhibited great overextension of the dummy's neck which is the cause of the high stress forces applied to the cervical vertebrae (Picture 11).

![Picture 11: Test 5/2; loose belt in the seat]

In test 6 with a loosened seat attachment (75 mm slack in the belt), differences arose due to the use of a P3/4 dummy for the first test series and a three-year-old dummy for the second test series. In spite of the lighter dummy in the first test, the head and chest were subjected to critical stress forces. The forward displacement of the head that was measured, on the other hand, was clearly below the limit. In the second test series, an absolutely critical acceleration value of 120 g was measured at the head and the permissible forward displacement of the head was clearly exceeded by 124 mm. The seat mounting was too loose and caused great hyperflexion of the dummy's neck in both test series, which is indicative of high stress forces applied to the cervical vertebrae (Picture 12).
### Table 6: Results of the misuse sled tests

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Seat Position</th>
<th>Sled Measurements</th>
<th>Dummy Type</th>
<th>Dummy Measurements</th>
<th>Abdomen Imprint</th>
<th>Head Excursion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$v_s$ [km/h]</td>
<td>$s$ [mm]</td>
<td>$a_{max S}$ [g]</td>
<td>HIC</td>
<td>$a_{res\ Head}$ [g]</td>
<td>$a_{res\ Thorax}$ [g]</td>
</tr>
<tr>
<td>1/1</td>
<td>-</td>
<td>51.0</td>
<td>530</td>
<td>TNO-P0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1/2</td>
<td>front</td>
<td>48.2</td>
<td>660</td>
<td>25.9</td>
<td>TNO-P0</td>
<td>-</td>
</tr>
<tr>
<td>2/1</td>
<td>-</td>
<td>51.0</td>
<td>530</td>
<td>TNO-P0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2/2</td>
<td>front</td>
<td>48.8</td>
<td>660</td>
<td>24.4</td>
<td>TNO-P0</td>
<td>-</td>
</tr>
<tr>
<td>3/1</td>
<td>-</td>
<td>51.0</td>
<td>550</td>
<td>TNO-P0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3/2</td>
<td>front</td>
<td>48.6</td>
<td>670</td>
<td>25.2</td>
<td>TNO-P0</td>
<td>-</td>
</tr>
<tr>
<td>4/1</td>
<td>-</td>
<td>51.0</td>
<td>570</td>
<td>TNO-P0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4/2</td>
<td>front</td>
<td>48.6</td>
<td>630</td>
<td>28.4</td>
<td>TNO-P0</td>
<td>-</td>
</tr>
<tr>
<td>5/1</td>
<td>-</td>
<td>50.1</td>
<td>520</td>
<td>23.6</td>
<td>TNO-P3</td>
<td>891</td>
</tr>
<tr>
<td>5/2</td>
<td>rear</td>
<td>48.8</td>
<td>660</td>
<td>24.4</td>
<td>US-3 yrs.</td>
<td>74.7</td>
</tr>
<tr>
<td>6/1</td>
<td>-</td>
<td>50.3</td>
<td>520</td>
<td>22.7</td>
<td>TNO-P3/4</td>
<td>776</td>
</tr>
<tr>
<td>6/2</td>
<td>rear</td>
<td>48.6</td>
<td>670</td>
<td>25.2</td>
<td>US-3 yrs.</td>
<td>119.8</td>
</tr>
<tr>
<td>7/1</td>
<td>-</td>
<td>50.3</td>
<td>550</td>
<td>22.5</td>
<td>TNO-P3</td>
<td>606</td>
</tr>
<tr>
<td>7/2</td>
<td>rear</td>
<td>49.2</td>
<td>690</td>
<td>26.4</td>
<td>US-3 yrs.</td>
<td>261.1</td>
</tr>
<tr>
<td>8/1</td>
<td>-</td>
<td>50.4</td>
<td>550</td>
<td>21.0</td>
<td>TNO-P3</td>
<td>1647</td>
</tr>
<tr>
<td>8/2</td>
<td>rear</td>
<td>49.3</td>
<td>680</td>
<td>24.5</td>
<td>US-3 yrs.</td>
<td>106.0</td>
</tr>
<tr>
<td>9/1</td>
<td>-</td>
<td>50.1</td>
<td>540</td>
<td>22.5</td>
<td>TNO-P6</td>
<td>594</td>
</tr>
<tr>
<td>9/2</td>
<td>rear</td>
<td>49.2</td>
<td>690</td>
<td>26.4</td>
<td>US-6 yrs.</td>
<td>37.0</td>
</tr>
<tr>
<td>10/1</td>
<td>-</td>
<td>50.1</td>
<td>520</td>
<td>23.2</td>
<td>TNO-P6</td>
<td>1564</td>
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<tr>
<td>10/2</td>
<td>rear</td>
<td>49.3</td>
<td>680</td>
<td>24.5</td>
<td>US-6 yrs.</td>
<td>143.8</td>
</tr>
</tbody>
</table>

(shaded contours define values over the ECE-R 44 limits)

- $v_s$ = Sled Speed
- $s$ = Breaking Path
- $a_{max S}$ = Maximum Sled Deceleration
- $a_{res\ Head}$ = Resultant Head Deceleration
- $a_{res\ Thorax}$ = Resultant Thorax Deceleration
- HIC = Head Injury Criterion
- US-Dummy = Humanoid-Systems

**Test Description**

Test No. A1 = 1st test series **ECE sled**

Test No. A2 = 2nd test series **car body**

- Test No. 1-3: ECE-Group 0; incorrect belt path
- Test No. 4: ECE-Group 0; seat installed in the wrong direction
- Test No. 5: ECE-Group I; 5-point seat belt with 25 mm slack
- Test No. 6: ECE-Group I; loose belt attachment (3-point belt with 75 mm slack)
- Test No. 7: ECE-Group I; incorrect belt path: lap seat belt placed around the seat at the front; shoulder belt not attached to the back of the seat shell
- Test No. 8: ECE-Group I; 4-point belt buckle located too high
- Test No. 9: ECE Group I; impact shield not used
- Test No. 10: ECE-Group II/III; booster cushions; shoulder belt passing beneath the arm
Test 7 shows the serious consequences that can arise from improper or incorrect belt positioning. Whereas the measurement data of the first test series only illustrate this risk based on excessive values for the forward displacement of the head, the car body test (second test series) depicts the dreaded risk very strikingly. The entire system tilted forward virtually without decelerating, thus slamming the dummy's body against the back of the front passenger seat (Picture 13). The head acceleration was measured at 261 g which indicates that critical to fatal injuries would have been sustained if this had occurred in a real accident. The chest acceleration also far exceeded permissible limits, although in this case it did not result from the forces exerted by the belt, but rather from the impact against the seat back.

Test 8 was designed to investigate the consequences that would arise when harness belt systems are used if the seat buckle is positioned too high (at the level of the costosternal junction). Furthermore, the seat was moved to the sleeping position as this was expected to produce even higher forces during an accident. Both tests produced considerable submarining effects (Picture 14). As the dummy slid forward through the seat, the buckle of the 4-point belt slid up into the region of the dummy's frontal neck leading to great cervical overextension and causing the head to hit against the buckle. The high acceleration forces applied to the head as well as the HIC value measured in the first test series indicate very serious head injuries would have been sustained in the event of a real accident. The forward displacement of the restraint system and the submarining, which was experienced in the car body test (second series of tests) resulted in a deep indentation in the back of the passenger seat caused by the dummy's legs. This in turn means that leg injuries must be expected in the event of a real accident.

When the impact shield of an impact shield system is omitted (test 9) and a six-year-old dummy is used (which exceeds the age group for which the restraint device is actually intended), the values for head and chest that were measured in both test series as well as the measured forward displacement of the head were found to be within defined limits. The moderate abdominal imprint that was detected in the first test series, however, indicates that injury might be possible in the abdominal region, something that is caused by the high position of the lap seat belt.

**ECE-Group II/III - (booster cushion) tests**

The dangers that are caused by a shoulder belt passing beneath the arm when a child is restrained using booster cushions are illustrated in test 10. In both test series, the forward motion of the dummy caused the shoulder belt to slip downwards into the abdominal region. The upper part of the body jackknifed virtually without being decelerated and this in turn caused the head to hit against the legs (Picture 15). The permissible forward displacement of the head was greatly exceeded and, in addition, the head was subjected to critical acceleration forces caused by the head hitting against the legs. The extreme constriction that the seat belt caused left a deep abdominal imprint which seems to predict severe injury to the abdominal region.
6 SEAT MOUNTING TESTS

6.1 ISOFIX

A "standardised rigid plug-in type connection" represents a completely novel type of mount. The system known as the ISOFIX system was developed by the International Organisation of Standardisation (ISO) [8] and is intended to simplify the installation of child seats and secondly to reduce misuse. In crash tests already conducted [17] the ISOFIX system was found to have significantly lower HIC values compared to a conventionally attached system and also lower chest deceleration values were measured. A major advantage of the ISOFIX system is that forward displacement of the head has been reduced in several tests by an average of approx. 140 mm, thus resulting in smaller forces being applied to the thorax (Fig. 7).

![Figure 7: Comparison of head movement between existing child restraints and ISOFIX seats in a crash (upright position)](image)

In the same study [17], the user-friendliness of the ISOFIX system was studied. Significantly fewer mistakes were made when installing the ISOFIX system than when installing conventional seats. Whereas approximately half of all current child seats were mounted incorrectly, misuse occurred in only about 10% of the cases when ISOFIX was used.

6.2 SEAT MOUNTING TEST METHODOLOGY

150 adult test subjects were asked to install and remove two child seats from an automobile using schematic operating instructions: one seat was a conventional ECE-Group I seat, the other was an ISOFIX system seat (prototype, ECE-Group I) (Picture 16). The test vehicle was equipped with four ISOFIX attachment points provided on the passenger seat. Using an observation questionnaire, a protocol was kept as the test subjects attempted to mount the seat including any special points or conspicuous incidents. At the conclusion of the test, the test subjects were requested to answer a few questions about the installation procedure they had just completed.

![Picture 16: ISOFIX prototype](image)

6.3 RESULTS

For the most part, parents with children (91%) succeeded in installing the seat, some 80% of them already having had experience with child protection systems. In order to gather enough instances of misuse in the study, different child seats were used as the comparison child protection system. In 135 out of a total of 150 cases, the test subjects succeeded in installing the comparison child protection system 1 (5-point system); the comparison child protection system 2 (5-point system), which in the opinion of the experts was more difficult to install correctly, was used in 15 cases.

Significantly fewer mistakes were made in installing the ISOFIX system (Fig. 8) than when the conventional seats were installed. Whereas the misuse rates for the conventional child seats ranged between 60 and 80%, misuse was registered in only 4% of the cases when the ISOFIX seat was installed, i.e. only 6 out of a total of 150 test subjects failed to correctly install the ISOFIX system.
The test subjects were also questioned about the advantages and disadvantages of ISOFIX. The majority said that ISOFIX was easier to install than a comparable conventional system. They were also convinced that ISOFIX is more stable and that the anchoring is better and that it would provide more protection for the child in the event of collision. The higher weight was seen as being a significant drawback as well as the fact that ISOFIX is only available for new cars. The ISOFIX system gained high acceptance in the study and most of the test subjects preferred it over the comparison child protection system that was used.

7 OVERALL DISCUSSION

The goal of the accident studies was to examine exclusively for restrained children what impact the type of restraint would have on injuries and the severity of injury. A new accident database entitled "Child Safety 90" was created and contains information pertaining to 593 restrained children in cars (between 6 to 12 years of age).

Irrespective of the type of restraint, there is a far greater danger that children will be injured in side collisions than in head-on collisions. For this reason, greater attention must necessarily be paid to this type of collision both when designing and developing child seats (side-wings, increased stiffness, head protection) and when drafting test regulations. Within the scope of the ISO Working Group WG1 Child Restraint Systems in Road Vehicles, an ad-hoc group was convened several years ago and is currently drawing up testing criteria and testing regulations for child protection systems in side-impacts on the basis of a worldwide accident database [11, 12].

Children who have been restrained only by a three-point seat belt or lap belt more frequently suffer injury than those restrained in a child restraint system. Not only the frequency of injury, but also the severity of injury is significantly higher when children are restrained solely by means of an adult seat belt. Children younger than six years of age have been found to suffer a higher risk of injury - when restrained only by an adult seat belt - than children between 6 and 11 years of age.

There are indications that point to differences in the degree of protection afforded by different types of systems. Compared with forward facing impact shields and 3-point belt child seat systems, forward facing harness belt systems show a trend on the whole to greater severity of injury in children. The effectiveness of rearward facing ECE-Group 1 systems has not yet been investigated as their market share in Germany is still very small.

The protection afforded by child protection systems can be reduced considerably in some cases due to the improper or incorrect use of child seats (misuse). On the whole, misuse was observed in 63% of the random samples studied where child protection systems were being installed. Serious misuse, that may well cause fatal injury, was in fact observed in one-third of all cases. Design, modifications and user education on how to install child restraint systems must be improved so that the protection afforded by such devices is not impaired. In the case of conventional child protection systems, particularly those systems, in which restraining the child and installing the child seat are two separate operations, are more likely to induce misuse than other systems.

Problems involving the proper fit of the child protection system in the vehicle (seat belt geometry, vehicle seats) led to moderate to serious misuse in the majority of cases. Here, cooperation between child seat manufacturers and motor vehicle manufacturers must emphasise combinations that fit or do not fit (e.g. positive or negative vehicle list). One of the crucial results of the interviews was that most parents are unaware of the existence of misuse and the dangers inherent in misuse. Well-targeted educational programs and better instructions for use ought to address this problem.

In order to determine what impact incorrect restraint would have on the forces applied to the dummies, frequently observed forms of misuse were reproduced in sled tests. Both the forward displacement of the head as well as the forces of acceleration to which the head and chest of the dummies were subjected and even the forces acting in the abdominal region were detected and registered. The maximum load values laid down in the test regulations (e.g. ECE-R 44) were exceeded in almost all tests, in some cases considerably. This confirms that incorrect or improper use of a child protection system can substantially reduce the protection afforded by this system. Serious to fatal injuries could well occur even in accidents that are less serious than the accident simulated in ECE-R 44 as a result of misuse.

The ISOFIX system has been tried and tested and represents a decisive improvement in the number of mistakes
that are made during installation (only 4% mistakes) compared with conventionally mounted child seats (more than 50%). This in turn can drastically reduce by a third the high percentage of severe misuse (33%) observed with conventionally mounted child seats. Previous tests also verify that ISOFIX subjects a child dummy to lower biomechanical forces than conventional systems both in the case of head-on [17] and even side collisions [12].

The respondents themselves evaluated the ISOFIX system as being better than the comparable conventional child seat. The majority stated that ISOFIX is easier to install than a comparable conventional system. They were also convinced that ISOFIX is more stable and provides more protection to a child in the event of a collision; the only point of criticism that was frequently made was the aspect of greater weight.

ISOFIX therefore appears to be a central element in the improvement of future child protection systems.

8 ESSENTIAL RECOMMENDATIONS

1. Child restraint systems should be designed in such a way that mistakes made when installing the seat and restraining the child are eliminated as far as possible. In so doing it should be borne in mind that children as well as adults must be regarded as the persons causing possible misuse.

2. The instructions for use should make possible dangers and risks due to misuse perfectly clear.

3. A misuse assessment should be incorporated as a test criterion into future test standards (ECE, FMVSS).

4. Child restraint systems should be designed and tested in such a way that in none of the possible positions (sleeping position) the defined test criteria should be exceeded.

5. Children should not advance from a child seat to booster cushion at too early an age. A body length of at least 110 cm (approx. 5 years of age) appears plausible.

6. There should be more publicity than in the past stressing that adult seat belts, when used as the sole restraint for children up to 150 cm (12 years of age), can provide only limited protection.

7. Parents should be given more information about the advantages and disadvantages of the different types of restraint systems, reference also being made to the fact that they may well be purchasing enhanced comfort at the expense of safety.

8. The lateral protection of child seats must be improved. A generally recognised and accepted side-impact test for child restraint systems must therefore be defined as soon as possible and incorporated into future regulations.

9. The child dummies required for a side collision test should be developed as soon as possible for the relevant age groups.

10. A "smart" passenger airbag - which is not activated, if a rearward facing child restraint system has to be mounted on the passenger seat - should be implemented in all new vehicles as soon as possible.

11. Belt force limiters must be studied in particular for the effect by installing conventional CRS (greater forward displacement of the child restraint system).

12. ISOFIX should be marketed as a standard as soon as possible. The results of both crash tests and field observations indicate a significant increase in the safety protection of child restraint systems. There have already been presentations of preliminary systems at the International Automobile Exhibition (IAA, 1997) in Germany.

REFERENCES


[18] FEDERAL STATISTICAL OFFICE OF GERMANY: Verkehr, Fachserie 8, Reihe 7, Verkehrsunfälle. Wiesbaden, Germany

APPENDIX A

Examples of degree of damage classification (Frontal collision)

Degree of Damage 2

Degree of Damage 3

Degree of Damage 4

Degree of Damage 5
Severity of injury to children restrained in different restraint systems

Child, rear left side
2 years, 1 month old, male
restrained in an impact shield system

No injury

Child, rear right side
2 years, 2 months old, female,
restrained in a 4-point-belt system

Injury:
Tibial fracture (due to leg impact against back of front seat)

AIS 2
**APPENDIX C**

**SYSTEM OVERVIEW**

Group 0: up to 10 kg
- *carrycot system*

Group 0/0+: up to 10/13 kg
- *infant carrier system rearward facing*

Group 0/I: up to approx. 15 kg
- *infant carrier rearward facing system*

Group I: 9-18 kg
- *4/5-point-belt system*

Group I: 9-18 kg
- *impact shield system*

Group I/I: 9-25 kg
- *3-point-belt system*

Group II: 15-25 kg
- *impact shield system*

Group II/III: 15-36 kg
- *booster cushion*