SAFETY REQUIREMENTS FOR THE TRANSPORT OF CHILDREN IN BICYCLE TRAILERS

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ABSTRACT

In recent years, a new means of transporting young children of up to approximately 6 years of age has become popular: the non-powered bicycle trailer.

The aim of this study is to show the advantages and the disadvantages of the different construction principles of the trailers on the market. Some test procedures have been developed to test safety performance. These procedures allow the manufacturer to check the current safety level using cheap and simple tests.

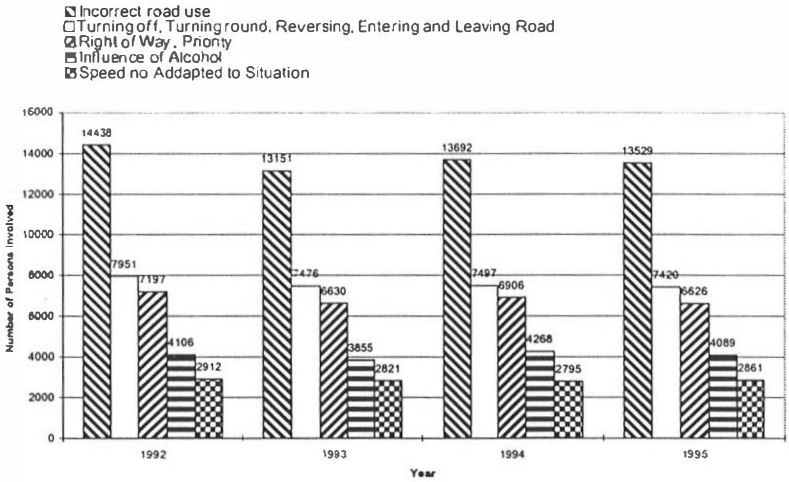
The test results will form the basis of a new DIN Standard. The American Society for Testing Materials (ASTM) has already prepared a "Trailer Standard". This draft Standard contains test methods similar to those developed in this study.

CYCLING has been gaining constantly in popularity over the last few years, both as an environmentally-conscious means of transport and also as a leisure activity (VDA, 1996). The bicycle trailer was developed to enable even very young family members to take part in the various cycling activities; the trailer constituted an alternative to the child bicycle seat. The increase in the numbers of bicycle trailers sold in recent years reflects the steadily increasing acceptance of this way of transporting young children. A market survey (Gehlen, 1996) shows that about 100,000 child bicycle trailers have already been sold in Germany.

In recent years, several investigations have been carried out into the safety of child bicycle trailers. Bicycle trailer designs and driving safety were the subject of a pilot investigation commissioned by the Federal Highway Research Institute (Wobben et al, 1994). The results were reviewed in the Special Committee on Two-Wheeled Vehicles of the Technical Committee on Automotive Engineering and the safety requirements were drawn up in the "Guidelines for Bicycle Trailers". Accident investigations and crash tests have also been carried out by "Bruderhilfe e.V." and "DEKRA AG" as well as by "Allianz-Zentrum für

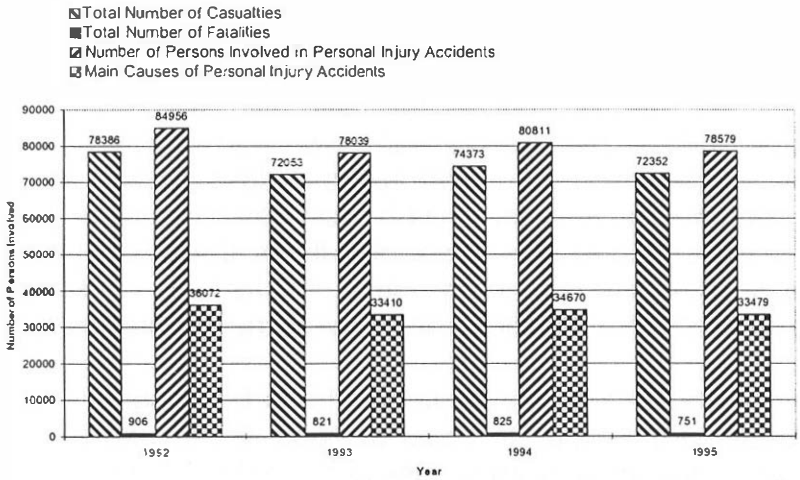
Technik" in conjunction with "TÜV Süd". Allianz compared the results with those from tests on child bicycle seats. The DIN Sub-Committee on Bicycle Trailers has been working on a draft safety standard since 1997 which contains special safety requirements regarding the transportation of children.

Figure 1: Error Behaviour of Those Involved in Bicycle Accidents (Statistisches Bundesamt, 1995)



Crash statistic can be used to determine the cyclists' behaviour pattern which are most frequently associated with accidents. This means that it is possible to select particularly relevant accident constellations. This procedure can also be applied to bicycle-trailer combinations. The effects of the errors made by those involved in two-wheeler accidents are shown in Figure 1.

Figure 2: Bicycle Accidents 1992-1995 (Statistisches Bundesamt, 1995)



The number of casualties, fatalities, persons involved and those mainly responsible for personal injury accidents over a period of 4 years are shown in Figure 2. The total number of accidents involving cyclists has decreased (Pöppel-Decker, 1995); however, all possibilities of further reducing the number of accidents and minimising their effects should be exploited.

The accident statistics (Statistisches Bundesamt, 1995), the accident analysis (Otte, 1993) (Der Minister für Wirtschaft,..., 1985) and the series of tests which had already been carried out were used inter alia to select the accident variants to be investigated. The effectiveness of the belt systems and the extent of the occupants` vertical displacement were other specific points of investigation.

SCOPE OF THE INVESTIGATION

Picking up on the investigations mentioned above, a project (Kalliske et al, 1997) was carried out by the Federal Highway Research Institute in co-operation with the "Rheinisch Westfälischer TÜV" (RWTÜV) in Essen on the passive safety of child bicycle trailers. A total of 4 tests with child bicycle seats were carried out, 21 crash tests and 13 tests relating to the headroom of child bicycle trailers. The test matrix is shown in Table 1.

Table 1: Test Matrix

Description of Test	Occupants	Number
Child bicycle seat tests; a car travelling at a speed of 30 km/h hits from behind a bicycle which is carrying an adult dummy and two child dummies (see Figure 3)	Cr 18M and P3 50% male adult dummy (on the bicycle)	1
Child bicycle seat tests; a car travelling at a speed of 30 km/h hits from the front a bicycle which is carrying an adult dummy and two child dummies (similar Figure 3)	Cr 18M and P3 50% male adult dummy (on the bicycle)	1
Child bicycle seat tests; a car travelling at a speed of 30 km/h hits centrally from the side a bicycle which is carrying one adult and two child dummies (in one of the tests the point of collision is the front child seat; in the other it is the rear child seat) (similar Figure 3)	Cr 18M and P3 50% male adult dummy (on the bicycle)	2
Impact against a stationary bicycle-bicycle trailer combination centrally from behind by a car travelling at a speed of 30 km/h (see Figure 4)	P3 and P6 50% male adult dummy (on the bicycle)	2
Impact against the trailer wheel hub of a stationary bicycle-bicycle trailer combination from the side by a car travelling at a speed of 30 km/h (similar Figure 4)	P6 (on the impact side) 50% male adult dummy (on the bicycle)	2
Impact of the front right edge of the bicycle trailer against a fixed obstacle (here a flower tub) while the bicycle-bicycle trailer combination is moving at a speed of 20 km/h (see Figure 5)	P3 and P6 (if possible) 50% male adult dummy (on the bicycle)	4
Crash tests involving the sled and the trailer chassis mounted on it (impact speed 20 km/h, deceleration distance 20 cm, retardation approximately 8 g (see Figure 6)	P3 and P6	8
Drop tests, in which the bicycle trailer is hung upside down at an angle of 45° to its longitudinal vertical plane at a height which means that the trailer is moving at a speed of 20 km/h on impact with the roadway (see Figure 7)	P3 and P6	5
Turning tests, in which the bicycle trailer with its correctly belted occupants is turned 360° about its longitudinal axis; measurement of the distance between the top of the helmet and the top edge of the trailer body at 0° and at 180° (no Figure)	P3 and P6	13

Figure 3: Test set-up for child bicycle seat (impact from behind)

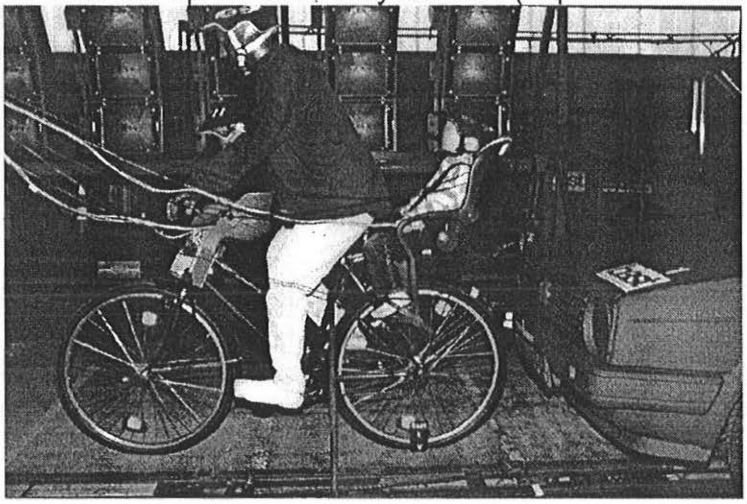


Figure 4: Impact against a stationary bicycle-bicycle trailer combination (impact from behind)

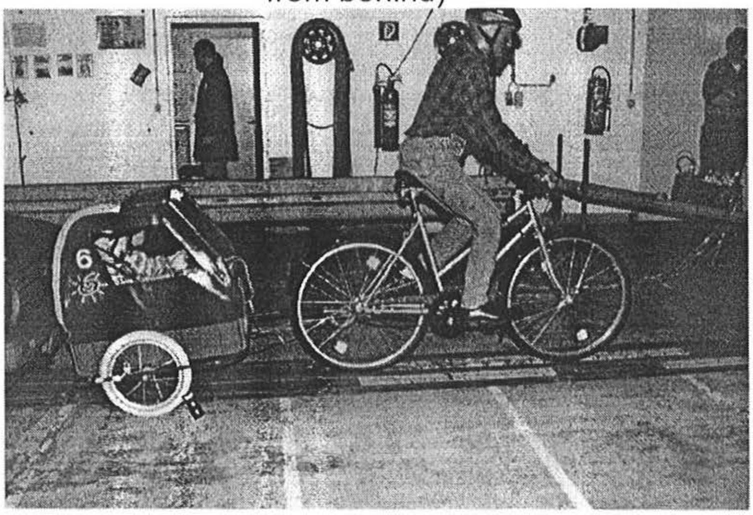
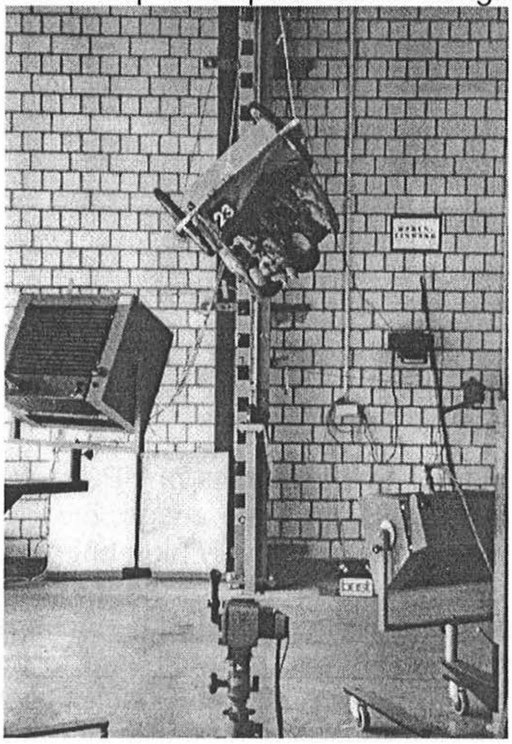


Figure 5: Impact of the front right edge of the bicycle trailer against a fixed obstacle

Figure 6: sled test set-up with bicycle trailer

Figure 7: Test set-up with upside down hanging trailer



The impact speeds were set at 30 km/h for the tests involving cars and at 20 km/h for those involving moving bicycles or bicycle-bicycle trailer combinations (this signifies a system consisting of a bicycle with a bicycle trailer coupled to it). The choice of which dummy or dummies was/were in the bicycle trailers depended on the type of test; the dummies represented children of 3 and 6 years of age (P3 dummy or P6 dummy) respectively. In the bicycle tests, a P3 dummy was placed on the rear child seat and a dummy representing a child of 18 months (Cr 18 M dummy) was placed on the front child seat. In all tests involving bicycles, each bicycle carried an adult dummy (50% man).

RESULTS

The loads which are permissible for adults in frontal collisions in cars (96/79/EG) were used to evaluate the loads on the child dummies in the tests conducted. The sole reason for this procedure was that there are no scientifically-founded load limits for children at the present time.

Results of tests involving bicycle trailers: Table 2 shows the head loads (HPC (Seiffert, 1985) and the 3 ms values) of the occupants in the bicycle trailer tests.

Table 2: HPC and 3 ms Values for the Head in the Trailer Tests

Child Trailer Tests							
	Test Number	Head Area					
		P6-Dummy			P3-Dummy		
		HPC-Value	3ms-Value[g]	Range [ms]	HPC-Value	3ms-Value[g]	Range [ms]
Impact from behind	1	306,7	69,3	34,8 - 76,9	693,3	95,3	36,8 - 41,0
	1a	800,6	115,7	30,1 - 259,4	953,0	117,3	32,4 - 35,4
	2	556,9	89,1	14,6 - 37,6	471,1	94,3	20,0 - 23,0
Side Impact	3	444,5	84,5	36,6 - 40,2	P3 dummy not used		
	4	529,7	89,8	38,1 - 44,7			
FlowerTub Tests	5a	87,9	41,9	890,3 - 898,7			
	5b	75,3	39,2	292,8 - 973,7			
	5c	160,4	53,0	57,2 - 1256,7			
	5d	95,8	46,2	999,9 - 1050,9			
Sled Tests	7a	26,6	15,5	109,3 - 390,2	39,4	16,7	77,3 - 125,7
	7b	19,4	12,6	106,0 - 130,5	11,8	9,9	93,4 - 106,9
	7c	68,9	26,5	58,5 - 309,1	33,4	17,2	124,8 - 394,1
	7d	37,4	31,0	112,3 - 118,9	16,2	12,4	35,4 - 45,0
	7e	37,9	17,2	114,0 - 121,0	32,3	14,1	101,0 - 154,1
	7f	12,3	11,0	96,0 - 110,6	30,0	20,0	361,0 - 366,1
	7g	31,4	14,4	120,1 - 127,9	26,1	16,5	104,3 - 123,3
	7h	40,8	14,8	128,8 - 132,4	28,0	15,5	109,7 - 112,8
Drop Tests	8a	152,4	26,7	85,1 - 109,0	154,6	59,8	65,9 - 110,8
	8b	334,6	76,1	105,6 - 110,7	808,6	105,5	72,0 - 77,7
	8c	528,8	97,2	120,1 - 124,1	612,0	94,9	89,9 - 94,7
	8d	232,5	59,5	80,3 - 86,2	304,6	75,7	67,4 - 76,2
	8e	no value	165,9	86,9 - 599,6	249,1	60,4	76,0 - 96,6

The biomechanical load limit for adults of HPC = 1000 was not exceeded in any of the bicycle trailer tests. In three cases, the HPC value exceeded 800, which, for an adult, represents a relatively high but not critical load.

An HPC value of 953 was measured for the P3 dummy in the test where the car drove from behind into a trailer model with a collapsible body which had not been stabilised (Test 1a). This can be attributed to the fact that the dummies came into direct contact with the car on impact. Following the collapse of the trailer body, the backs of their heads hit the front of the vehicle. This therefore produced relatively high acceleration values.

The P3 dummy had an HPC value of 808 in the drop test 8b which involved a trailer with an aluminium pan and fabric-covered tubular framework. The reason for this was that the side wall of the body was not sufficiently stable to protect the P3 from the heavy impact against the ground. The same model with roof padding (drop test 8a) produced an HPC value of 154 for the P3 dummy.

The permissible acceleration value for the head of 80 g was exceeded in the

- Impact test from behind
- Impact test from the side
- Drop test.

These high loads occurred in tests where the occupants were in the area hit directly by the car (tests 1 to 4) or where there was direct or indirect contact with the roadway (tests 8b to e).

Table 3 shows the chest loads which occurred during the tests with bicycle trailers.

Table 3: 3 ms Values in the Chest Area during Bicycle Trailer Tests

Child Trailer Tests					
	Test Number	Chest Area			
		P6-Dummy		P3-Dummy	
		3ms-Value [g]	Range [ms]	3ms-Value [g]	Range [ms]
Impact from behind	1	81,8	23,7 - 32,4	71,9	36,1 - 39,1
	1a	78,2	26,9 - 29,9	56,7	27,1 - 33,4
	2	46,1	24,5 - 30,5	53,5	28,8 - 33,2
Side Impact	3	62,0	16,9 - 19,9	P3 dummy not used	
	4	78,7	27,2 - 31,6		
Flower Tub Tests	5a	13,2	42,6 - 896,0		
	5b	11,9	974,5 - 977,5		
	5c	12,5	31,2 - 34,2		
	5d	10,5	41,7 - 1056,4		
Sled Tests	7a	11,1	67,8 - 77,5	12,8	103,3 - 134,7
	7b	12,6	77,8 - 83,6	11,0	91,3 - 94,7
	7c	14,6	113,6 - 448,7	19,0	80,4 - 172,5
	7d	12,8	73,8 - 106,8	11,7	77,7 - 109,7
	7e	19,0	199,3 - 291,6	9,7	56,6 - 68,2
	7f	13,2	83,2 - 86,2	11,0	95,4 - 144,6
	7g	13,7	85,1 - 92,6	16,2	81,0 - 84,1
	7h	11,8	79,8 - 88,2	12,3	78,8 - 81,8
Drop Tests	8a	21,0	111,4 - 114,4	26,8	123,2 - 126,2
	8b	38,5	108,7 - 111,7	43,0	76,0 - 81,7
	8c	39,7	110,1 - 113,9	29,9	92,1 - 98,4
	8d	30,2	90,2 - 97,8	30,3	77,0 - 403,8
	8e	23,5	110,7 - 115,6	31,0	84,4 - 90,0

Table 3 shows that several 3 ms values were either above or just below the limit value for chest acceleration of 60 g. The 3 ms limit values were exceeded in the following test constellations:

- Impact test from behind (test numbers: 1, 1a for P6 and 1 for P3)
- Impact test from the side (test numbers: 3, 4 for P6).

The high chest loads occurred in the tests where the bumper was at the height of the dummies' chests at the time of collision. There was, however, no direct contact with the front of the vehicle causing the collision, except in Test 1a, in which the trailer body collapsed. The factors causing the loads were internal (indirect) collisions (internal collisions are defined here as collisions with internal parts of the trailers, e.g. with stiffend), the mass of the colliding car relative to that of the bicycle trailer and the comparatively high speed of the cars in these collisions where the brakes were not applied.

The sled tests served predominantly to test the restraint systems; the "collision with obstacle tests" put a heavier load on the structure of the trailer. In both tests the dummy loads were low. With the exception of the head loads in the flower tub tests, all head and chest accelerations were less than 50% of the permissible limit value for adult vehicle occupants. With the exception of Test 5c, the HPC values were less than 10% of the permissible load value. Various components of the trailer were damaged in the sled and flower tub tests, e.g:

- Metal eyelets screwed to the chassis
- Plastic buckles for the adjustment of the belt slack or to tie down the seat cover
- Belt and seat cover stitching and the seat cover itself were torn.

In the 'collision with obstacle tests' none of the trailers was damaged in such a way that its safety function would have been impaired. In the tests where the impact was not central, this caused the trailer to overturn.

In the drop tests, plastic deformations occurred to the body structure which led to a reduction in the occupant protection area; this could result in injuries to the occupants. Table 4 shows the horizontal plastic deformations of the trailer.

Table 4: Deformation Distances of the Trailer Structures

Description of Model	Horizontal Plastic Deformation
Model AI1 with additional roof padding	8.5 cm
Model AI2 without additional roof padding	17 cm
Model GI2	8.5 cm
Model D3	5.75 cm
Model I1	11 cm

The measurements listed in the Table show that there were some considerable deformations to the body structure of the trailers (Model AI2). They also show that even simple structural changes, such as reinforcement of the roof (here additional roof padding, Model AI1) can produce more rigid and padded and thus safer structures.

In the tests where the belt forces were measured, none of the measurements reached the theoretically calculated force of 1726 N for a P6 dummy. The basis for this calculation was the mass of a P6 dummy (22 kg), an impact speed of 20 km/h and a deceleration distance of 20 cm.

Based on the 'headroom tests', it was possible to determine the vertical displacements of the occupants. This enables statements to be made about the effectiveness of the restraint systems, e.g. when the trailer turns onto its side or overturns completely, as it is possible to determine whether the occupant`s head leaves or remains within the trailer`s protection area. The measurement results are shown below in Table 5. The 'differences' were arrived at by subtracting the measured headroom in the 180° position from that in the 0° position.

Table 5: Differences and Average Values of the Measured Headroom
'+' - inside the contours of the trailer
'-' - outside the trailer structure

Model	Headroom [mm]					
	Position 0°		Position 180°		Differences	
	P3	P6	P3	P6	P3	P6
AI	11,0	4,5	-0,5	-6,0	11,5	10,5
AII	10,0	3,0	-3,5	-10,0	13,5	13,0
B	3,5	0,0	-4,0	-9,5	7,5	9,5
C	11,5	4,5	9,0	0,0	2,5	4,5
D to the Crosstube	9,0	4,0	0,0	touched the tube	9,0	no
to the Roof	11,5	6,5	3,0	penetrated the roof	8,5	statement
E	10,5	6,0	0,0	-4,5	10,5	10,5
F	12,0	5,0	5,5	-1,5	6,5	6,5
GI	7,5	3,0	-6,0	-10,5	13,5	13,5
GII	7,0	2,0	6,5	1,0	0,5	1,0
HI	2,0	-3,0	-2,5	-11,5	4,5	8,5
HII	11,0	2,0	0,0	-6,0	11,0	8,0
I	17,0	12,0	4,5	-0,5	12,5	12,5
J	11,0	4,0	1,5	-2,5	9,5	6,5
Average Value	9,6	3,8	1,0	-5,1	8,6	8,7

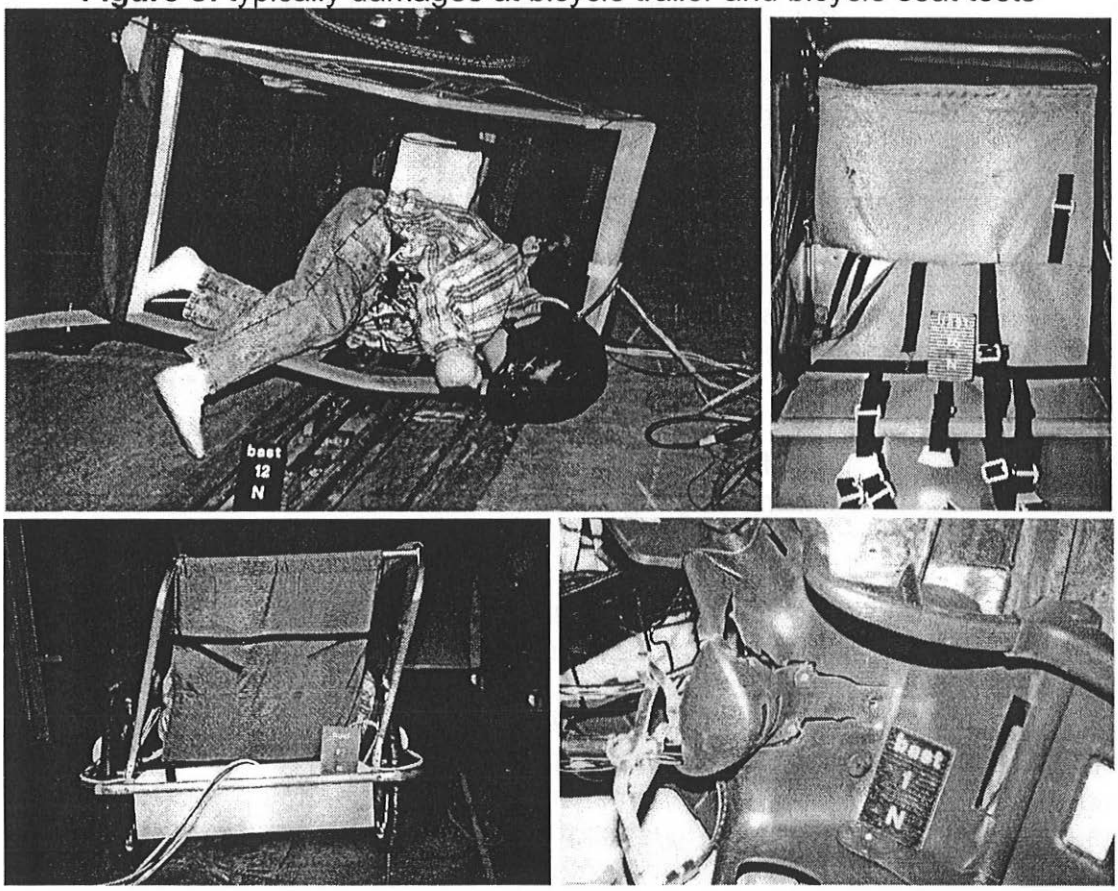
The results for models C (FGRP design) and GII (model with plastic pan and fabric-covered metal tubular framework) were comparatively good. The differences were smaller than 5 cm and the P6 still has 1 cm headroom in GII in the 180° position (dummies hanging head-downward). These models had 5-point belts attached to the solid chassis or to the FGRP structure (model C) of the bicycle trailer. There were very high differences for other models, due inter alia to the belt systems being attached to the seat cover, which gave considerably in the 180° position. 3-point belt systems which were not adjustable at the shoulder allowed for high vertical displacements, as the occupants moved around within the belt system. A suitable means of limiting the vertical motion of the trailer occupants is to use a lap belt.

RESULTS OF TESTS INVOLVING CHILD BICYCLE SEATS: the low number of impact tests with child bicycle seats (4 tests with 3 different forms of collision) allows only limited statements to be made concerning the loads on the seat occupants (children) in cases of accidents involving bicycles with child seats. Therefore we paid no further attention to these results at this point.

DISCUSSION

The results of the tests show that increased loads (which in some cases even exceed the limit values) occur in the head and chest areas when a car collides with a trailer, particularly when the occupants come into direct contact with the front of the vehicle. If, in the course of the tests, the occupants come into contact only with internal parts of the vehicle structure, almost all of the load values produced are below the permissible limit values for adults. The occupants were not catapulted out of the trailer in any of the various types of test. In the "collision with an obstacle" tests, in the course of which the trailer always turned over sideways, the P6 dummy sometimes protruded out of the body which meant that there was direct contact with the roadway. In addition to examining the movement behaviour of the occupants, the 'sled tests' and the 'headroom tests' served predominantly to test the restraint systems. In the course of these tests, damage occurred to the fastening points of the restraint systems, the belt adjustment device, the fastening eyelets of the seat cover and the belt stitches. It was seen that the reliability of the belt system in conjunction with the rigidity of the trailer structure have a decisive influence on the occupants` injury risk. Possibilities for stabilising the structure of the trailers can be derived from the drop tests and the deformation to the body structure which was in some cases considerable. (see Figure 8)

Figure 8: typically damages at bicycle trailer and bicycle seat tests



A comparison of transportation in bicycle trailers and on bicycles is only possible to a limited extent because of the insufficient number of tests carried out using child bicycle seats. Table 8 compares the advantages and disadvantages of each method of transport as they arose from the tests performed.

Table 8: Comparison of the Possibilities of Transportation

Transportation in Bicycle Trailers	Transport on the Bicycle in Child Seats
(+) The heights of the bicycle trailers and cars showed that the chest of the children was at the level of the bumper and the head at that of the car bonnet; however, generally, according to the trailer design and the nature of the collision, no direct contact between vehicle and trailer occupants took place. (+) Children were not catapulted out of the trailers in the tests. (+) A low risk that children and trailers are run over by the cars. (-) Internal collisions are possible due to the trailer body (-) Too little headroom and weak restraint systems can lead to increased risk of injury when the trailer overturns	(+) No contact of the child`s head or upper body on initial impact with the car (-) Possible contact with the colliding vehicle and with the roadway in the further course of the accident (-) In the event of a collision where the children remain in their seats, the risk of injury is increased by the height of the fall (-) The weight of the cyclist and of the bicycle and also the many bicycle parts, which can lead to injuries, conceal an increased risk of injury for the child (-) High risk of the children being run over by other vehicles, as they are frequently catapulted out of the child seats and then lie unprotected on the roadway

CONCLUSIONS

The results of the tests form the basis for drawing up possibilities for improving the bicycle trailers currently on the market. These are concerned with general statements on improving the safety level of bicycle trailers and not with the assessment of individual makes. The conclusions lead on the one hand to the presentation of objectively necessary design changes and on the other hand to the derivation of test methods for testing specific aspects of passive safety in bicycle trailers.

IMPORTANT DESIGN CHARACTERISTICS for a high level of safety are:

- the use of a stable chassis structure (e.g. a closed pan) which should be at the height of car bumpers in order to prevent the trailer being run over;
- that the body structure is linked to the chassis in such a way that there is no chance of it becoming separated in the event of an accident;
- that the body structure is reinforced to the extent that the body shape is retained in the event of the trailer being overturned, therefore providing sufficient survival room for the occupants;
- that the body structure is of a height sufficient to ensure that occupants with safety helmets at no time protrude above the body height ;
- belt width not less than 25 mm;
- that the fixture points of the belt system are designed in such a way that the test of the seat-belt mounting strength which is suggested below is passed and as little belt slack as possible exists;

- that seat covers, if used, are fixed and stitches positioned in such a way that no damage occurs in the tests which correspond to the test procedure proposed below.

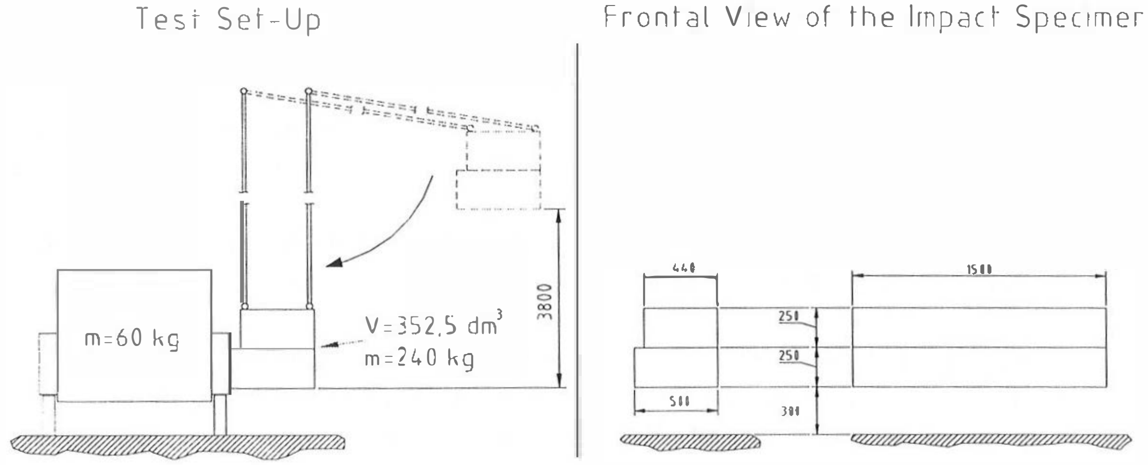
On account of the large differences in childrens` body sizes relating to their age and sex, the manufacturer should specify the largest and smallest body size and the maximum and minimum age of the children for which his product is intended (Kreinjobst, 1997). In addition to this, a list should be attached to the item description giving the possible extras (e.g. baby pan), which are suitable for use in conjunction with the respective trailer.

TEST PROCEDURES - Four simple test procedures were derived from the knowledge gained in the investigations in order to provide the manufacturers of child bicycle trailers with a proven means of investigating the safety level of their products and to make it possible to assess the passive safety of child bicycle trailers uniformly.

Pendulum Test: This test serves to load the bicycle trailer as if a car had driven into the trailer at a speed of 25 km/h. For this purpose a pendulum is used which is shaped like the front of a car and suspended from four cables (Figure 9). The test specimen has the dimensions given in the illustration below and a weight of 240kg. In the test, the pendulum is raised to a height of 3.8 m and then released. The test specimen then moves downwards describing a curve and hits the object being tested (bicycle trailer) at the lowest point of its path (horizontal). The vertical impact area of the test specimen on the object being tested should be 300 mm above the roadway.

This test should be performed once from the rear and once from the side.

Figure 9: Test Set-Up for the Pendulum Test and Representation of the Impact Specimen



Headroom Test: For this test, apparatus should be used which allows the trailer to turn 360° about its longitudinal axis. During the test, the bicycle trailer should be occupied by two dummies (a P3 dummy and a P6 dummy) or by two test objects, which correspond in weight and body size to a P3 and a P6 dummy, respectively. The headroom of the test dummies is determined in two situations: sitting upright in the travelling position and turned 180° with the head downward. In each case the gap is measured between the top of the helmet and the top of the trailer body. The head in the helmet may not protrude beyond the body structure in any of the positions.

Body Structure Load Test: For this test, the bicycle trailer should be fixed upright without wheels on an even surface in such a way that it cannot move during the test. The trailer may only be fixed in position at points on the chassis. From an angle of 45° diagonally from above, a force of 1,5 kN is then applied to the body for at least 15 seconds. The horizontal deformation of the body under load (a quasi static load) may not exceed 8 cm.

Belt System Strength Test: Similarly to ECE R 14, this test is designed to check the strength of the belt systems. The test object should in this instance correspond to those of ECE R 14 but be adapted in its dimensions to the body size of a 6 year-old child. The test force for each individual bicycle trailer belt system should be 1.5 kN.

The results of this investigation can not provide a complete and conclusive assessment of the passive safety of the two methods of transportation (in a child safety chair on a bicycle or in a bicycle trailer); however, they point towards the conclusion that transport in a bicycle trailer is the less dangerous alternative.

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