The Effects of Pre-Impact Braking on Dynamic Test Performance of Child Restraint Systems (CRS) in Frontal Impacts

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Abstract

The evaluation of CRS regarding dynamic performance in frontal impacts such as complying to Safety Standards, is based upon tests on dynamic test rigs. The usual rigs accelerate the test seat up to the required impact speed such as 30 mph or 50 km/h over a relatively short test rig length. Depending on this length and the onset of acceleration, the dummy will be initially pushed backward into the seat back, thus creating additional slack by increasing the space between the dummy's torso and the safety system.

This condition is different to the majority of real-life-accidents, where pre-impact braking will occur and force the child to be in close contact with the safety system before impact.

The paper investigates the effects pre-impact braking will have on the dynamic performance of CRS and compares the data with standard test results. For this purpose a pre-impact brake system is added to a dynamic rig. The results show that pre-impact braking has a positive effect on the dynamic motion and leads to a significant reduction of head acceleration for forward-facing CRS in frontal impacts.

The Occurrence of Pre-Impact Braking in Real-Life-Accidents

In spite of the large number of published investigations on real-life accidents, very few reports indicate the percentage of cases in which pre-impact braking ("panic braking") occurred. This seems to be surprising for two reasons:

1) It may be assumed that most of the accident-questionnaires are asking for pre-impact braking in order to calculate the collision speed.

2) It may be expected that the actual position of the occupant just prior to impact - in particular vis-à-vis the restraining system - has an effect on the injury severity. The position of the car occupant, however, is mainly determined whether braking just prior to impact did occur or not.

In 1969 the University of Birmingham, UK, examined causes and effects of road accidents (1)*. It was stated that in 48% of rural and motorway and in 36% of urban accidents skidding occurred.

In 1977 the HUK-Verband, Germany, informed about the reaction of car drivers involved in accidents with 27.000 cars regarding pre-

* Numbers in parentheses designate references at the end of the paper

impact braking as follows (2):

36,7%	hard braking
13,3%	partly braking
50%	no braking reaction.

More detailed information is included in an assessment of approx. 10.000 accidents by Daimler-Benz/Dekra (3;4). For passenger cars the data for pre-impact braking is stated as follows:

56,3%	braking, with skidding
12,0%	braking, without skidding
31,7%	no braking.

In addition, Daimler-Benz/Dekra investigated the braking rate of drivers in cars, in which most probably the rate of children being involved was remarkably lower than for the average of all cases:

57,4%	accidents during night
56,0%	accidents caused by alcohol
50%	very young, inexperienced male drivers

Summarizing, the Daimler-Benz/Dekra accident evaluation indicates that in more than 68,3% cases, in which children as car passengers were involved, pre-impact braking occurred.

Child Dummy Motion due to Pre-Impact Braking

The effect of pre-impact braking in dynamic tests will be influenced by the sequence of motion of the child dummy. In order to investigate potential hazards to unrestrained children from deploying airbags, the child motion during panic or pre-impact braking has been studied in the past. Kaleps/Marcus (5) performed computer simulations with - among other variables - three child body sizes (6, 3 and 2 1/2 years old) and three levels of braking decelerations (0,5g, 0,72g and 0,9g). The typical motion sequence for a 3 year old child during 0,50 g braking is reprinted under fig. 1.

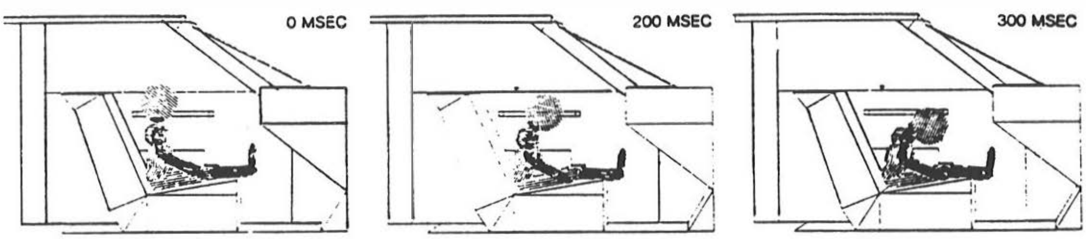


Fig. 1: Three-Year-Old Child Motion During 0.50g Panic Braking Deceleration (5)

The sequence of motion in fig. 1 shows remarkable forward movement of the dummy's head, little movement of the chest and no movement of the pelvis.

Stalnaker et a. (6) used dummies and anesthetized baboons to determine the influence of pre-impact braking on positions and postures of un-restrained children in motor cars, decelerated at a mean value of 0,76g. Particular considerations were made regarding the effect of muscle tension or the lack of it. Stalnaker et al. anticipate that upon muscle tension the child would maintain his/her upright posture while sliding forward on the seat. Without initial muscle tension the child's torso would rotate forward about its hips. Further parameters that may influence the child's motion are the design and softness of the car seat cushion (respectively design of the CRS), the friction between the seat cover and the child's clothing, thus promoting a forward movement of the dummy's head rather than the chest.

Simulation of Pre-Impact Braking on Test Rig

The usual test rigs accelerate a trolley, on which a real or simulated car seat is installed, over a given distance up to the desired impact speed. Due to the restriction of space available, the initial acceleration is usually so high that the dummy is forced into the seat back and will stay there as long as the trolley keeps accelerating.

The final and on most sleds relatively short no-acceleration-length just prior to impact will not re-position the dummy into its original neutral position. Therefore tests on such test rigs are done with additional, undesirable slack, which inevitably may effect the test results. These tests do not sufficiently resemble such real-life-accidents where - due to pre-impact braking - the child is forced into the restraining system just prior to impact.

Note: Within the Child Safety Standard ECE44 only for infant car beds this situation has been somewhat considered by placing the infant dummy into a central position and fixing it towards the rear wall (see ECE44, paragraph 8.1.3.6.3.1).

A schematic set-up of an accelerating test rig - as being installed at BRITAX RÖMER Ulm/Germany - is shown in fig. 2.

In order to simulate pre-impact braking, the trolley has been equipped with an additional brake system as shown (fig. 3).

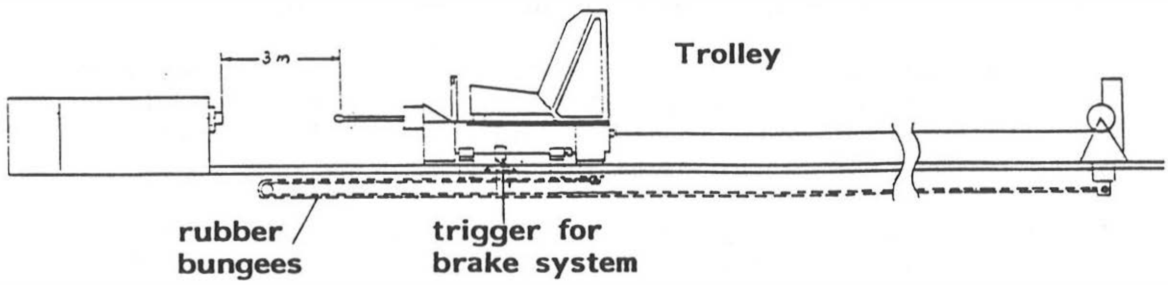


Fig. 2: Test Rig

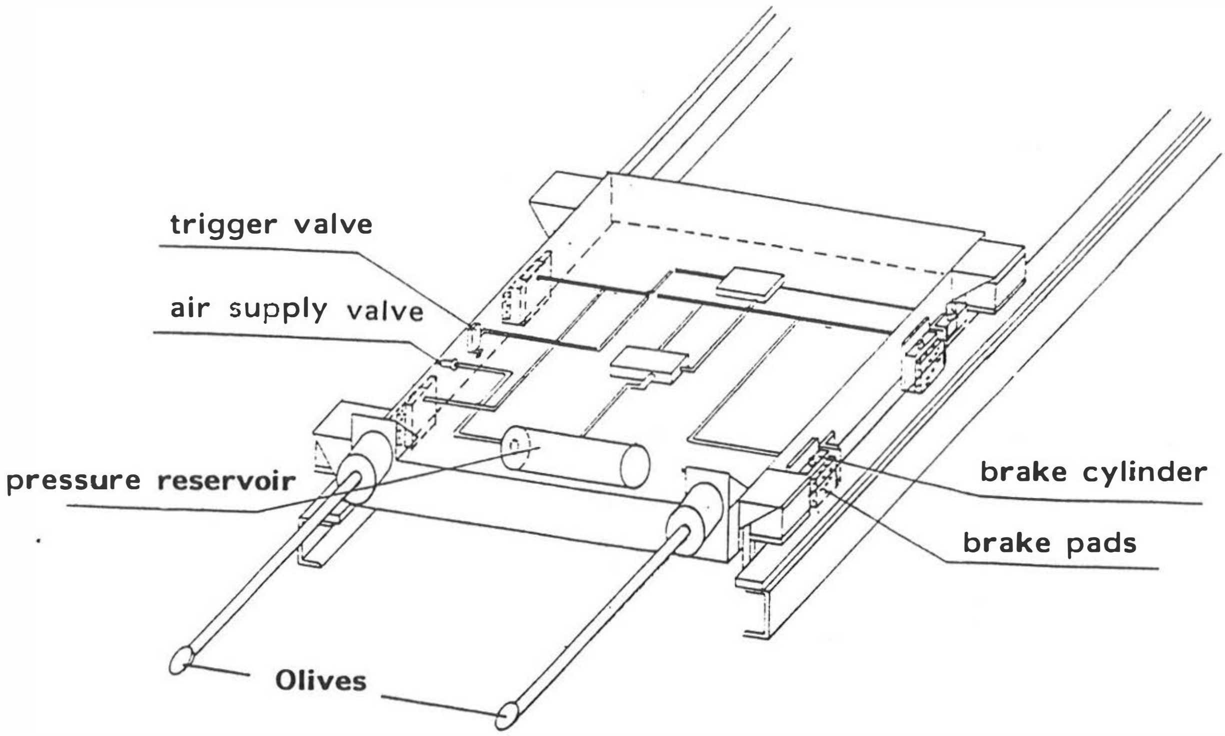


Fig. 3 Brake System on Test Rig

The 4 braking pads are automatically actuated over a length of the final 3 metres before impact, triggered when the trigger valve is passing a pre-set point on the slide rails. An air pressure reservoir will then release the compressed air at a pressue of 7 bar to the 4 braking pads.

The braking effect is initially counteracted and therefore reduced as long as the rubber bungees are still under tension resulting in an initially slow onset of deceleration.

Under consideration of these given test conditions, the impact speed after braking was set to approx. 40 km/h in order to allow for sufficient forward movement of the dummy. At this impact speed the brake system decelerated the trolley from approx. 43 km/h to the desired impact speed, resulting in a braking deceleration of approx. 0,3 g.

As to be seen in the test films taken, this effect forced the dummy into a position comparable to fig. 1 at 200 ms with partial, but still no firm contact between dummy and restraining system. This braking condition is called "short braking" in tables 1-4.

Again due to the given design of the test rig, it was not possible to simulate the effect of "hard braking" long enough to force the dummy fully into the restraining system before impact. In order to simulate the "hard braking"-condition as included in tables 1-4, the dummy was manually pre-postured towards the restraining system before accelerating the trolley, similar to the dummy's posture in fig. 1 after 300 ms. This was done by placing polystyrene behind the dummy's back and tape around its head.

Finally, for comparison purposes, tests were done in the usual "no-braking"-condition at the same impact speed of approx. 40 km/h.

Comparison Tests with various CRS

Comparison tests for the 3 braking conditions "no braking", "short braking" and "hard braking" were done with the following CRS:

a) Forward facing child seat as per ECE44 age group 1 with 4-point harness, (fig. 4a)

b) Forward facing child seat, age group 1, with impact table, (fig. 4b)

c) Forward facing booster cushion, age group 2, with standard 3-point belt, (fig. 4c)

d) Rearward facing baby shell, age group 0, with 3-point harness, (fig. 4d)

CRS a) and b) were secured by 2-point belts, c) and d) by 3-point belts, all using the ECE-44 anchorage points.

Fig.4 a): 4-Point Harness

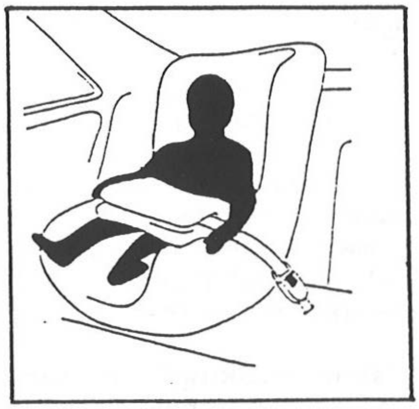


Fig.4 b): Impact Shield

Fig.4 c): Booster Cushion

Fig.4 d): Baby-Shell, rearward facing

Fig. 4: Schematic presentation of the four different CRS

TNO child dummies relevant to the various age groups were used. Since the dummy position in the rearward facing group 0 baby shell is the same for the "short braking"- and the "hard braking"-condition, these tests were combined.

In order to highlight the effect of pre-impact braking, the test data published in this paper are restricted to horizontal and vertical head deceleration and head excursion as the most prominent test criteria. It should be added that the reduction of chest deceleration is substantially lower than for head acceleration. In line with the results by Kaleps/Marcus (5) and Stalnaker (6), the test films proved that upon pre-impact braking the dummy rotates forward about its hips with noticeable movement of its head but little movement of the chest.

Fig. 5 a) - 5 d) show typical curves for head deceleration in x- and z-direction for the 3 different braking conditions.

Regarding head deceleration peaks longer than 3 ms were measured and are listed as x_{max} and z_{max} in table 1 to 4.
Furthermore the time after impact when these peaks are occurring is listed and also the point when the head deceleration is starting. This was to confirm that pre-impact braking will lead to an earlier deceleration of the dummy, preferably already during the phase of sled deceleration.

Test Results

In tables 1 to 4 resp. fig 5 a) to 5 d) the effect of pre-impact braking versus the "no braking"-condition is illustrated.

a) All CRS tested show only little variance of the head excursion. Simulation of muscle tension as described by Stalnaker (6) with the dummy maintaining an upright posture while sliding forward may lead to a reduction of head excursion. However, this effect was not simulated during these tests.

b) Upon "short braking", forward-facing CRS as per table 1 to 3 resp. fig. 5 a) to 5 c) show a reduction of the horizontal head acceleration of 20-42% and 18-34% for vertical head deceleration.

   If direct contact between the dummy's torso and the restraining system can be achieved, as assumed for "hard braking", the reduction versus "no braking" is substantially higher:

   for horizontal head deceleration: 50-61%
   for vertical head deceleration: 48-61%.

   Regarding CRS with impact shield, these results are confirmed by Langwieder/Hummel/Felsch/Klanner (7), who compared both the dummy in an upright position with "no braking" and in an inclined position similar to the "hard braking"-condition. For the CRS as per fig. 4 b) a reduction of 55% of the max. resultant head deceleration was reported.

   The effect of pre-impact braking for dummies in forward facing CRS may be compared with the effect of pre-tensioner systems on adult seat belts, where a reduction of head acceleration of approx. 30% is achieved with even higher reductions for belts with additional slack (8).

Tests with rearward facing CRS (fig. 4 d) with its relatively low head deceleration in the first place show little effect of pre-impact braking as per table 4 resp. fig. 5 d).

c) Depending on the type of forward-facing CRS, pre-impact braking may reduce the time between trolley impact and the begin of head deceleration resp. the time of max. head deceleration peaks. Whereas the harness system with its rather late head deceleration peaks shows little difference, the impact shield CRS in table 2 has a very positive effect. The early begin of the head deceleration for the impact shield system, caused by the direct connection of the seat belt with the impact table, was further brought forward with a noticeable reduction of the peak loads. A similar effect was achieved by the booster cushion.

   Both the impact shield and booster cushion utilize the advantage in participating in the simultaneous sled deceleration. Their max. head deceleration peaks occur during the phase when the sled itself is still decelerating.

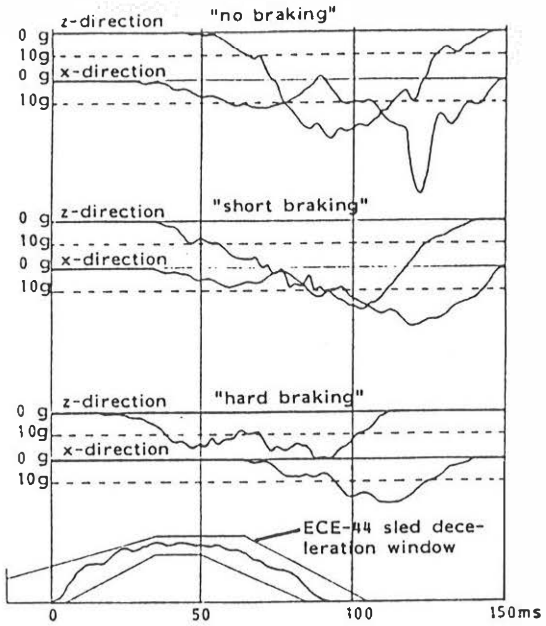
   The initial favourable data for the level and time of head deceleration and peak loads for the rearward facing CRS were hardly affected by pre-impact braking.

d) Considering the above results, it can be assumed that the head deceleration of forward facing CRS in frontal impacts under pre-impact braking conditions show data comparable to rearward facing CRS.

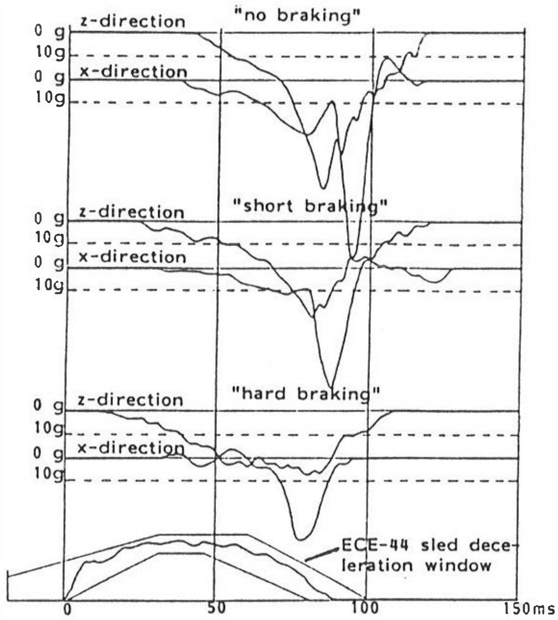
Discussion

Tests on dynamic sleds with trolleys accelerated to impact speed over a short length represent a worst case crash condition. This condition does neither reflect the test results of a dummy impacted in its initial "neutral" position, nor particularly with partial or close contact between dummy and restraining system due to pre-impact braking.

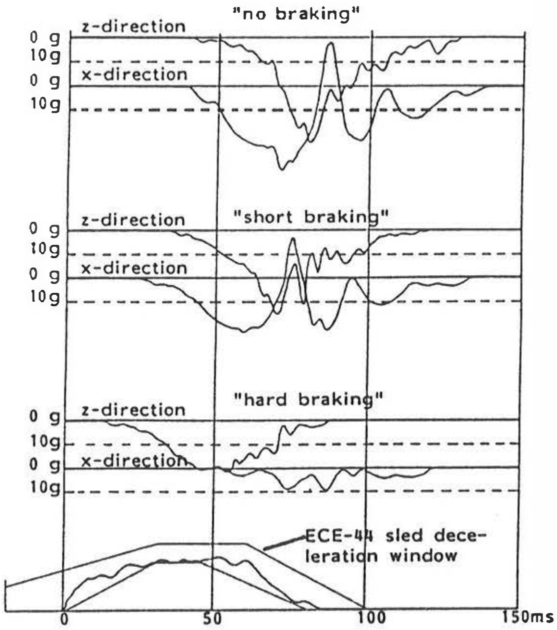
Tests on this sled type performing frontal impacts according to CRS safety standards - such as ECE44 - are applying this worst case condition since many years, thus allowing for additional safety margin for forward facing CRS. Therefore the author does not propose to substitute the present test method by pre-impact braking as standard test procedure. However, upon introducing head deceleration as a criterion into safety standards, it is proposed to consider the significant reduction of head acceleration due to pre-impact braking.



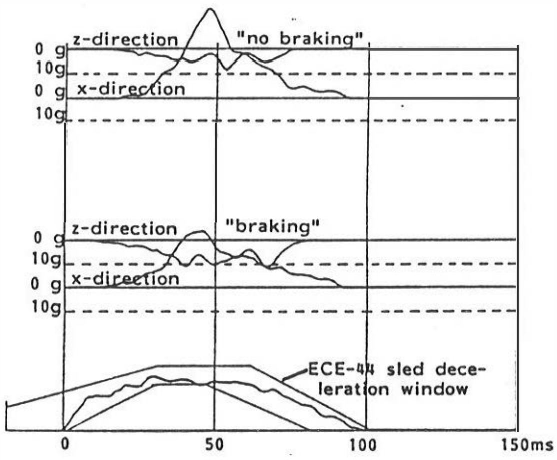
5 a): 4-Point Harness System (see fig. 4 a)



5 b): Impact Shield System (see fig. 4b)



5 c): Booster Cushion (see fig. 4 c)



5 d): Baby Shell (see fig. 4 d)

Fig. 5: Head Deceleration shown above Sled Deceleration for different braking conditions

TEST CRITERIA		"No Braking"	"Short Braking"	Variance of Head Accel. to "No Braking"	"Hard Braking"	Variance of Head Accel. to "No Braking"
Impact speed	(km/h)	40,3	40,2		38,7	
Max. sled deceleration	(g)	22	21		23	
Head excursion	(mm)	475	475		495	
Max. horizontal head deceleration x_{max}	(g)	36	21	- 42%	18	- 50%
Max. vertical head deceleration z_{max}	(g)	39	27	- 31%	19	- 51%
Begin of horizontal head deceleration after impact t_x	(ms)	40	38		36	
Begin of vertical head deceleration after impact t_z	(ms)	44	33		25	
Time of max. horizontal head deceleration after impact $t_{x\ max}$	(ms)	106	114		110	
Time of max. vertical head deceleration after impact $t_{z\ max}$	(ms)	93	101		91	

Table 1: **Child seat, ECE group 1, with 4-point harness TNO P3 dummy, 3 years**

TEST CRITERIA		"No Braking"	"Short Braking"	Variance of Head Accel. to "No Braking"	"Hard Braking"	Variance of Head Accel. to "No Braking"
Impact speed	(km/h)	39,8	38,4		38,9	
Max. sled deceleration	(g)	25	19		25	
Head excursion	(mm)	430	420		415	
Max. horizontal head deceleration x_{max}	(g)	73	47	- 36%	31	- 58%
Max. vertical head deceleration z_{max}	(g)	64	42	- 34%	25	- 61%
Begin of horizontal head deceleration after impact t_x	(ms)	36	32		26	
Begin of vertical head deceleration after impact t_z	(ms)	41	29		26	
Time of max. horizontal head deceleration after impact $t_{x\ max}$	(ms)	92	85		78	
Time of max. vertical head deceleration after impact $t_{z\ max}$	(ms)	84	81		78	

Table 2: **Child seat, ECE group 1, with impact shield, TNO P3 dummy, 3 years**

TEST CRITERIA		"No Braking"	"Short Braking"	Variance of Head Accel. to "No Braking"	"Hard Braking"	Variance of Head Accel. to "No Braking"
Impact speed	(km/h)	40,3	39,2		38,6	
Max. sled deceleration	(g)	18	18		19	
Head excursion	(mm)	320	290		350	
Max. horizontal head deceleration x_{max}	(g)	30	24	- 20%	10	- 61%
Max. vertical head deceleration z_{max}	(g)	40	33	- 18%	21	- 48%
Begin of horizontal head deceleration after impact t_x	(ms)	37	27		20	
Begin of vertical head deceleration after impact t_z	(ms)	52	43		20	
Time of max. horizontal head deceleration after impact $t_{x\ max}$	(ms)	89	85		54	
Time of max. vertical head deceleration after impact $t_{z\ max}$	(ms)	75	70		41	

Table 3: **Booster cushion, ECE group 2, with standard 3-point belt, TNO dummy P6, 6 years**

TEST CRITERIA		"No Braking"	"Braking"	Variance of Head Accel. to "No Braking"
Impact speed	(km/h)	40,4	39,6	
Max. sled deceleration	(g)	17	18	
Head excursion	(mm)	455	450	
Max. horizontal head deceleration x_{max}	(g)	29	25	- 14%
Max. vertical head deceleration z_{max}	(g)	8	8	± 0
Begin of horizontal head deceleration after impact t_x	(ms)	22	22	
Begin of vertical head deceleration after impact t_z	(ms)	22	22	
Time of max. horizontal head deceleration after impact $t_{x\ max}$	(ms)	44	44	
Time of max. vertical head deceleration after impact $t_{z\ max}$	(ms)	53	56	

Table 4: **Baby-shell, ECE group 0, with 3-point harness, TNO dummy P 3/4, 9 months**

Evaluation of Real-Life-Accidents

A large number of evaluations of real-life-accidents have been published. Among others, Langwieder et al. (7) have evaluated 865 cases in Germany with restrained children and summarized the results as per table 5. It should be noted that children were using forward facing CRS comparable or identical to fig. 4 a) to 4 c).

Age (years)	Injury Severity MAIS 0	1	2	3	4/5	6	Total
0	77	10	2	1	1		91
1	159	24			1	1	185
2	132	28	2			1	163
3	98	16	1				115
4	74	12	2				88
5	59	13					72
6	39	8					47
7	26	8					34
8	9	8					17
9	13	2					15
10	16	3					19
11	9	3	1				13
12	4	2					6
Total	715	137	8	1	2	2	865
%	82.7	15.9	0.9	0.1	0.2	0.2	100.0

Table 5: Distribution of the injury severity MAIS and of the age of restrained children in cars

Notwithstanding the fact that the majority of real-life-accidents occur at speeds below the comparable impact speed of standard CRS testing, the high percentage of uninjured children is striking. Test results on test rigs done under the usual "no braking"-conditions at impact speeds even well below 50 km/h do not indicate such a high level of uninjured children (MAIS 0) as shown in table 5. The reduction of loading as shown in the preceding chapters may suggest that among other reasons pre-impact braking in view of its high occurrence in real-life-accidents plays a major part for reducing the injury level of restrained children.

Summary

- From a number of accident evaluations the conclusion can be drawn that in more than 2/3 of all accidents in which children as car occupants are involved pre-impact braking will occur.
- The test results in this paper as well as prior papers prove that pre-impact braking will bring a child dummy into full or partial contact with the restraining system.
- Standard child dummy testing on the usual accelerating test trolleys cause - different to accidents with pre-impact braking - additional slack and represent a worst case crash condition.
- Depending on the degree of pre-impact braking, the level of head deceleration of dummies in forward facing CRS can be substantially reduced in comparison to the no-braking condition.
- Rearward facing CRS are hardly affected by pre-impact braking regarding head acceleration.
- The positive effect of pre-impact braking on the performance of forward facing CRS can be compared with pre-tensioner systems on adult seat belts.
- In real-life-accidents pre-impact braking assumingly plays a major part for reducing the injury level of restrained children.
- It is proposed to consider the positive effect of pre-impact braking on head deceleration within the requirements of CRS safety standards.

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