COMPARISON STUDY OF TWO 3-YEAR OLD CHILD DUMMIES (Part 572 and P3) IN A HARNESS TYPE CHILD RESTRAINT SYSTEM

by

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ABSTRACT

The frontal crash response of the Part 572 3-year old child dummy in an American child restraint system was compared with that of a child cadaver in a previous study. In this study a new 3-year old dummy, the P3 which is prescribed in the ECE Regulation 44 was compared with both the behaviour of the Part 572 dummy and that of the cadaver.

In addition the MADYMO mathematical crash victim simulation program was used in an extensive sensitivity study for detailed analysis of the differences between both dummies. Simulations were performed with varied dummy characteristics like mass distribution and joint range of motions.

Differences between both dummies and the cadaver were shown and explained by means of the results of the sensitivity study. The kinematical effect of the vertebral column of the cadaver was found to be simulated in a more realistic way by the P3 than by Part 572 dummy. Some recommendations on how to improve future child dummy design are given.

INTRODUCTION

Child restraint system designs exhibit widely varying configurations with restraint concepts ranging from simple belt harnesses to padded impact shields. For the evaluation of the crash performance of these systems several dummy types are available. In this study two types for representing the 3-year age group will be compared with each other: the Part 572 and the P3 dummy.

The Part 572 dummy is prescribed in the United States Regulation FMVSS 213 and the P3 in the ECE Regulation 44. Beside this 3 year old dummy three similar dummies are specified in the ECE Regulation, representing age groups of 9 months, 6 and 10 years, respectively.

Performance evaluation of child dummies is impeded by a lack of biomechanical data on the crash behaviour of children. The only data available on restrained child cadavers in well-instrumented and well-defined crash conditions are reported in references (1) and (2). In reference (1) the behaviour of four child cadavers (age: 2.5, 6, 6 and 11), restrained by a lapbelt with impact shield were described. Significant differences were reported between the flexion behaviour of the vertebral column of these cadavers and of the two dummies (type Alderson VIP-6C).

In reference (2) the behaviour of a 6-year child cadaver (with approximately the anthropometry of a 4-year old child) in a harness type child restraint system was described and compared with the behaviour of the Part 572 dummy. These tests were carried out at the Highway Safety Research Institute (HSRI) in Michigan. In this study similar differences between the cadaver and dummy vertebral colomn response were observed.

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It is the objective of the present study to compare the behaviour of the P3 with the Part 572 and to confrontate the test results with the cadaver performance in the HSRI tests. The impact sled tests were carried out in identical child restraint systems as used in the HSRI-tests.

The tests at the HSRI were conducted according to the test procedures specified in the proposed FMVSS 213 (1974). Since the test seat prescribed in this old standard was not available in our laboratory it was decided to conduct the comparison tests according to the specifications in the present United States child restraint Regulation FMVSS 213 (1980). As a consequence the test data can only be compared qualitatively with the cadaver behaviour.

For explanation of observed differences in the performance of both dummies a mathematical model will be employed to analyse the possible influence of variations in the anthropometric characteristics of both dummies. Consequently the work reported here, includes a detailed comparison of the most important anthropometric data of both dummies.

ANTHROPOMETRY OF THE P3 AND THE PART 572 DUMMY [1)]

Differences in the dynamical behaviour of the two dummies will be mainly due to differences in their geometrical and material properties. In this section a comparison of relevant dimensions, mass distribution data and joint characteristics will be presented. Most of the measurements at the Part 572 dummy were carried out at the Highway Safety Research Institute in 1977 and were reported earlier (2).

Dimensions - The most relevant dimensions with respect to the behaviour in a frontal collision are summarized in Table 1 and Fig. 1. The differences in dimensions between both dummies are found to be small except for distance J (top of head to neck-torso connection) which is found to be 0.045 m less for the P3 than for the Part 572.

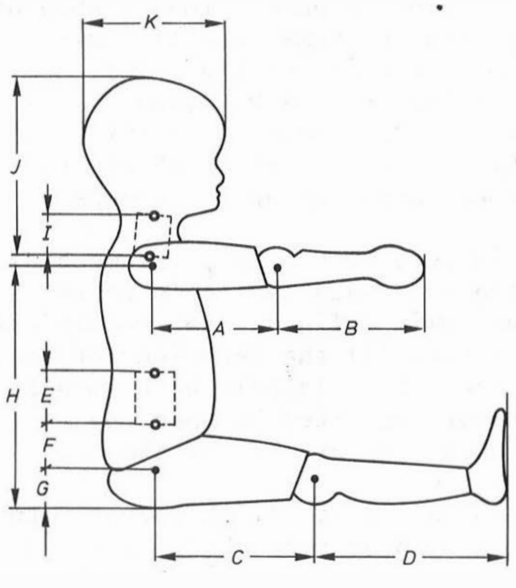


Fig. 1 Side view of child dummy with dimensions (Refer to Table 1)

1) Part 572 dummy: 3 year dummy supplied by Alderson Research Laboratories (specified in CFR Part 572, Dec., 1979).
P3: 3 year dummy supplied by TNO (specified in ECE Regulation 44).

Table 1 Comparison of some Dimensions (refer to Fig. 1)

		Part 572 3-yr m	P3 m
	Stature	0.98	0.98
	Sitting height	0.57	0.56
A	(shoulder center - elbow center)	0.125	0.135
B	(elbow center - upper most point of hand)	0.24[2)]	0.185[3)]
C	(hip center - knee center)	0.23	0.245
D	(knee center - lower most point of foot[1)])	0.245	0.245
E	(spine length)	0.08	0.085[4)]
F	(hip center - bottom of spine)	0.065	0.065
G	(hip center - floor)	0.06	0.055
H	(shoulder center - floor)	0.32	0.32
I	(neck length)	0.080	0.06[4)]
J	(bottom of neck - top of head)	0.25	0.205
K	(head length)	0.175	0.175

1) Dummy with leg and foot at right angles.

2) Fingers are in extension.

3) Fingers are flexed.

4) Distance bottom lower neck ring to center head-neck pivot.

Mass distribution - Table 2 presents the mass (accuracy 0.01 kg) and the moment of intertia of the dummy segments. The moments of inertia which are defined about the left-right axis through the center of gravity, are measured with a torsional pendulum (3). Depending on the magnitude of the moments of intertia, the accuracy varied between 1 and 2 %. To facilitate comparison between the data from both dummies the values of individual dummy parts in the thorax are assigned to an upper torso part and to a lower torso part. The location of the centers of gravity is given in Table 3. The accuracy of this measurement is 0.01 m.

Joint characteristics - The analysis of the joint characteristics of both dummies will be limited to the neck and the spine joint. The design of these joints in both dummies is completely different.

In the Part 572 dummy the spine and the neck each are represented by one rubber cylinder while in the P3 for both joints a set of 5 deformable elements is used which are interconnected by a cable (Fig. 2). At the top of the neck one extra element is connected (representing the atlas-axis joint) on which the head is mounted by means of a hinge joint. As a consequence of these different design principles the flexibilities of the neck and spine in both dummies are not identical: the joints in the P3 are much more flexible than in the Part 572 dummy (see Table 4).

Table 2 Mass and Moments of Intertia of the Dummy Segments

Segment	Mass		Moment of Inertia	
	Part 572 (kg)	P3 (kg)	Part 572 (kg m²) x 10 -3	P3 (kg m²) x 10 -3
head 4)	2.64	2.525 1)	13.0	10.5
neck	0.46	0.26 2)	0.76	-
upper torso 3)4)	3.41	3.67	16.1 5)	20.0
lower torso 3)	2.26	2.44	5.5	7.0
upper arms	0.64	1.09	2.7	3.5
lower arms + hands	0.51	0.66	3.7	2.0
upper legs	3.54	2.905	23.1	24.5
lower legs + feet	1.39	1.67	9.8	11.0
Total	14.85	15.23		

1) Including neck bolt.

2) Without neck cable.

3) Calculated from individual dummy parts; mass of torso skin and foam (Part 572 dummy), of spine element (both dummies), of abdomen section (P3) and of spine and neck cable (P3) are partly (50 %) assigned to upper torso and partly (50 %) to lower torso.

4) Without accelerometer.

5) Including ½ neck.

Table 3 Location of the Center of Gravity of the Dummy Segments

Dummy segment	Part 572 (m)	P3 (m)	Comment
head	0.090	0.075	distance to top of head
upper torso 1)	0.185 2)	0.190	distance to hip joint
lower torso 1)	0.055	0.015	distance to hip joint
upper arms	0.055	0.060	distance to shoulder joint
lower arms + hands	0.085	0.095	distance to elbow joint
upper legs	0.080	0.135	distance to hip joint
lower legs + feet	0.135	0.130	distance to knee joint

1) Upper and lower torso are defined in Table 2.

2) Including ½ neck.

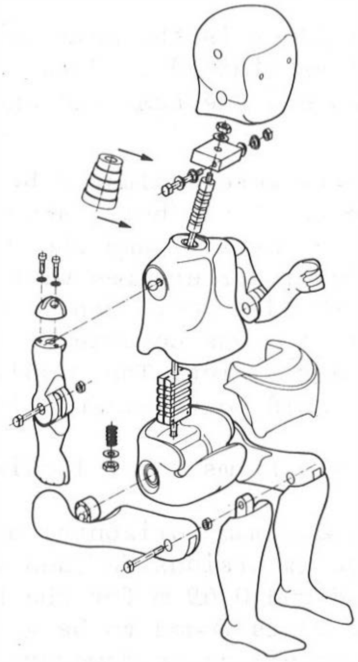


Fig. 2 Exploded view of P3 dummy

Table 4 Rotation of neck and spine in forward direction (flexion)

	neck		spine	
	Part 572 (degr.)	P3 (degr.)	Part 572 (degr.)	P3 3) (degr.)
free rotation 1)	0	35 3)	0	30 3)
forced rotation 2)	35	85 3)	18	45 3)

1) External load on joint zero (except for gravity forces).

2) External torque on joint ≈ 20 Nm.

3) Dependent on definition of neutral joint position.

EXPERIMENTAL METHOD

The sled impact comparison tests were conducted, according to the test procedures specified in FMVSS 213 (1980). A sled deceleration-time profile of nominally 30 mph velocity change with an average deceleration of 20 g was used. The dummies were seated in a five-point harness child restraint system (type Strolee Wee Care), which was installed on the standard bench seat prescribed in this child restraint regulation. The child seat was attached to the sled by a normal car lapbelt and with its special backstrap. Load cells were used on the right and left car lapbelt segments and on the backstrap. The dummies were instrumented with triax accelerometers in head and chest and were provided with targets on head, shoulder, elbow, upper leg and knee joint. High speed movies (1,000 frames/sec) were taken to document the kinematics of the dummies. Three tests were carried out with the Part 572 and five tests with the P3 dummy. The child restraint system was replaced after each test.

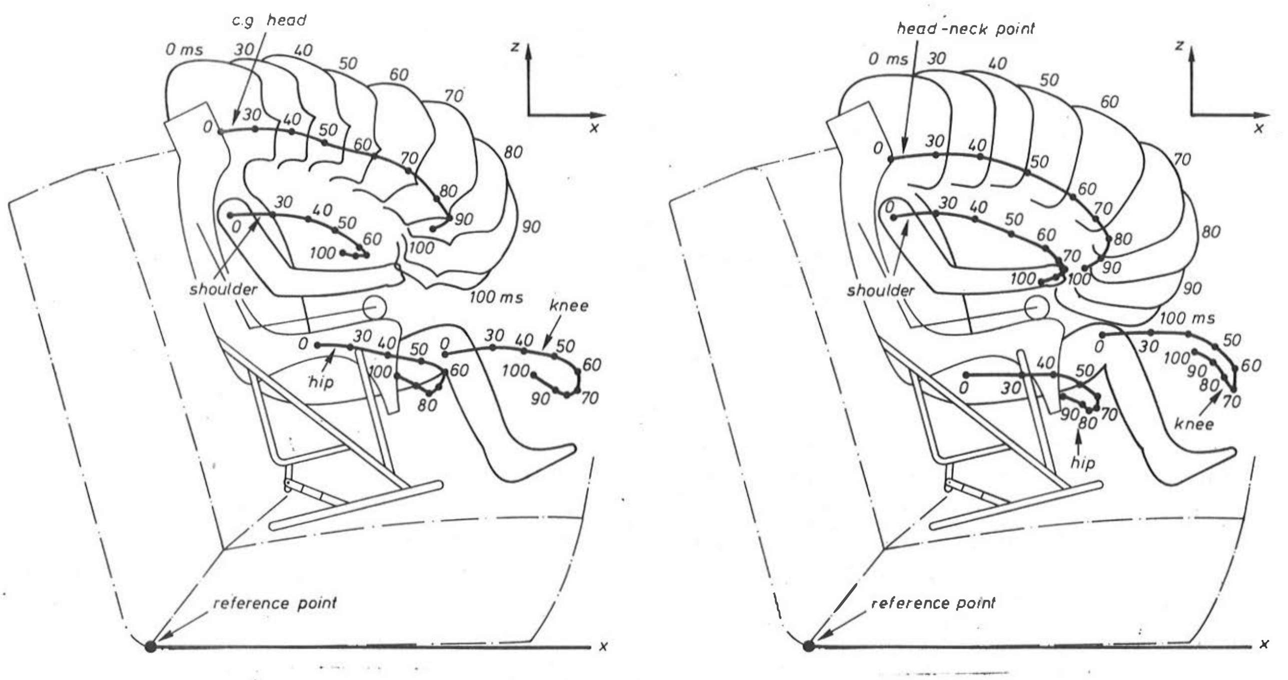
EXPERIMENTAL RESULTS

Since the comparison of the two child dummy types is the main objective of this paper, the results presented here will be limited to data that describe the dummy behaviour: i.e. the kinematics and the head and chest accelerations.

Kinematics - The high speed films of the tests were evaluated by means of a motion analyser. Fig. 3 shows the displacements of the head, shoulder and knee targets as a function of time. For both the Part 572 and the P3 dummy the kinematics of one of the three tests is shown. Differences with the other two tests were found to be small (less than 0.03 m deviation in maximum head and knee excursion). Because the pelvic region was covered by the child restraint system no targets were located on the hipjoint. The displacement of the hipjoint, which is included in Fig. 3, could be determined from two targets on the upper leg.

On the basis of this analysis of the highspeed films the following can be concluded:

- there are no significant differences in the maximum horizontal head and knee excursions of both dummies. The average excursions defined according to FMVSS 213 (1980) were 0.64 m for the head and 0.69 m for the knee;
- the average rotational head velocity of the P3 is found to be greater than for the Part 572 dummy. Also the head excursion in downward direction is greater (difference 0.06 m), causing the P3 head to strike the armrest of the childrestraint system;
- the deformation of the spine is much greater in the P3 than in the Part 572: the reduction in distance between P3 shoulder and hip at 100 ms is about 30 % and only 10 % in the Part 572 dummy.



Part 572 dummy P 3 dummy

Fig. 3 Kinematics of Part 572 and P3 dummy

Accelerations - The resultant head and chest accelerations and their components in anterior-posterior and inferior-superior direction (with respect to a reference frame connected to head and chest, respectively) are shown in Fig. 4. Results of one test which each dummy type are presented. The three tests with the Part 572 dummy showed almost identical head and chest acceleration-time functions. In the five tests with the P3 dummy greater differences in the head and chest accelerations were found, so the repeatability of the P3 in this configuration is judged to be less good than that of the Part 572 dummy.

The P3 dummy has to be calibrated before each test. In one of the tests this simple calibration procedure was not carried out, which was found to

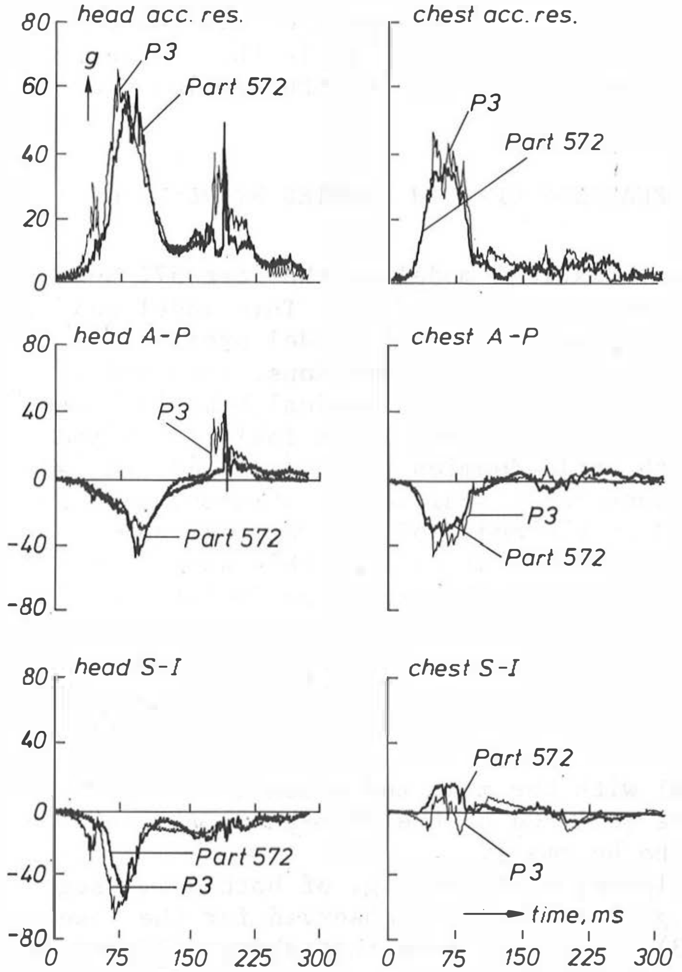


Fig. 4 Head and chest accelerations of Part 572 and P3 dummy

result in relatively large high frequency vibrations in the head accelerations (In the ECE Regulation 44 no head acceleration measurements are required).

It can be observed from Fig. 4 that the maximum resultant head and chest accelerations for the P3 are slightly greater than for the Part 572 dummy which is mainly due to the more oscillating nature of the P3 curves. The HIC-value is found to be 693 for the P3 compared to 582 for the Part 572 dummy.

COMPARISON BETWEEN THE BEHAVIOUR OF THE TWO DUMMIES AND A CHILD CADAVER

The results of the sled tests conducted at HSRI with a child cadaver and a Part 572 3-year dummy in an identical child restraint system were presented on the 23 rd Stapp Car Crash Conference (2). Since these test conditions were slightly different any comparison can only be globaly.

The most significant difference between cadaver and Part 572 dummy in the HSRI-tests was in the motion of the head and torso: analysis of the cadaver experiment showed rather large deformations of the spine in comparison to the dummy experiment (about 25 % reduction of the distance between shoulder and hip at 100 ms), a greater average rotational head velocity and also a greater downward head displacement causing the face of the cadaver to strike the armrest.

Analysis of the comparison tests, presented in the preceeding sections showed similar tendencies for the P3 dummy: greater spine deformations, a greater average rotational head velocity and the dummy head striking the armrest. Based on this it can be concluded that for the tested child restraint system the P3 gives a more realistic simulation of the cadaver kinematics, than the Part 572 dummy. The observed deviations between the head and chest accelerations in the HSRI-tests on the one hand and those in the TNO tests on the other hand prevent any conclusion about which of both dummies predicts these accelerations the best.

ANALYSIS OF THE DIFFERENCES IN THE BEHAVIOUR OF BOTH DUMMIES BY MEANS OF MATHEMATICAL SIMULATIONS

At the 23 rd. Stapp Conference a mathematical model of the Part 572 3-year child dummy in a child restraint system was presented (2). This model was formulated with the general program package MADYMO (5). Model predictions were found to agree quite well with experimental observations. This model will be employed here to study the influence on the dynamical behaviour of the differences in the dummy parameters in more detail. In Table 1 - 4 the most important characteristics of both child dummies are summarized. The effect of differences in the dummy parameters is analysed by simulating on or more of the characteristics of the P3 in the model of the Part 572 dummy. We will not present all the variations carried out to keep this paper compact in format, while moreover only the effect on a limited selection of output parameters will be considered. The results presented here relate to the effect of 7 relevant variations on 6 output quantities (see Table 5). A complete and detailed documentation of a sensitivity study with this model (the effect of 85 parameters changes on 33 output quantities) is presented in reference (3).

Variations 1 and 2 in Table 5 deal with the mass and moments of inertia. The Part 572 dummy segment masses are replaced by the P3 segment masses. The influence of these changes is found to be small.

Variations 3 and 4 relate to the location of the c.g. of both dummy segments. Significant differences in c.g. location were observed for the lower torso and the upper leg (see Table 3). It can be seen that these differences only slightly affect some of the output quantities.

The only striking deviation in dummy dimensions is in the head-neck length (distance J in Fig. 1 and Table 1). An indication of the influence of this deviation is predicted by variation 5 (a displacemant of the neck-torso pivot in upward direction). The head excursion and head accelerations are found to be strongly affected by this change.

Variations 6 and 7 finally deal with the neck and spine characteristics. In these calculations the P3 neck and spine properties, respectively, are approximated. In comparison to the effect of the mass distribution (variations 1-4), the effect of these joint characteristics is found to be rather large.

Variation 6 (P3 neck stiffness) showed a greater average rotational head velocity of which the magnitude was close to the experimental observations.

Table 5 Influence of Dummy Parameters on Occupant Response: Parameter Variations with Mathematical Model of Part 572 3-year Dummy

Parameter Variation	Hor.Head Excursion (m)	Ver.Head Excursion (m)	Hor.Hip Excursion (m)	Lin.Head acc. %	Lin.Chest acc.(3ms) %	HIC %
1. Mass of P3 segments	-	-	-	+ 2	- 4	+ 2
2. Moments of inertia of P3 segments	-	-	-	+ 1	-	+ 4
3. Shift c.g. upper leg 0.06 m in direction of knee	-	-	-	-	- 2	-
4. Shift c.g. lower torso 0.04 m in direction of hip	-	+ 0.02	-	- 4	+ 1	- 5
5. Shift Neck-Torso pivot 0.05 m in upward direction	- 0.035	- 0.05	-	- 15	-	- 32
6. Neck characteristics of P3	-	+ 0.08 1)	-	+ 11	+ 1	+ 19
7. Spine characteristics of P3	+ 0.04	+ 0.07 1)	-	- 18	+ 1	- 13

\- Influence less than 0.01 m or 1 %.

1) In these mathematical simulations vertical head displacement is not prevented by contact with the arm rest.

Although the mathematical model predicts an increase of the horizontal head excursion by a more flexible spine (variation 7 in Table 5) , such an increase was not observed in reality. This is because this effect is eliminated by the shorter head-neck length of the P3 dummy as indicated by variation 5 in Table 5.

DISCUSSION AND CONCLUSIONS

In the present study the performance of the P3 dummy in a child restraint system with harness was compared with the Part 572 3-year child dummy. The most significant difference observed between both dummies was in the motion of the head and the torso: The P3 showed a much greater deformation of the torso and consequently a greater head excursion in downward direction. Horizontal head and hip excursion were, however, identical for both dummies. On the basis of calculations that were conducted with a mathematical model of the Part 572 dummy it was shown that differences in mass distribution between both dummies hardly affected the dummy performance. The observed differences in kinematics could mainly be explained by a greater and thus more realistic range of motion in the spine and neck of the P3 dummy. The mathematical model used in this analysis was reported in an earlier study (2) and can be considered as validated for this specific test set up.

The dummy test results were compared with the behaviour of one cadaver in a sled test carried out at HSRI. It could be observed that the P3 gives a more realistic simulation of the cadaver kinematics than the Part 572 dummy.

In other words, for this type of restraint systems (i.e. child seat with harness) the P3 is more humanlike with respect to the kinematical behaviour than the Part 572 dummy. It should be noted, however, that this conclusion is based on only one test with one cadaver.

In this study only a limited number of tests were conducted with each dummy, which makes any definite conclusion on the repeatability of both dummies questionable. Nevertheless there is a strong indication that the repeatability of the head and chest accelerations is better for the Part 572 than for the P3 dummy. The repeatability of the maximum horizontal head and knee excursions in this test showed no significant differences. The lower repeatability of the head and chest accelerations of the P3 dummy may partially be explained by the free range of motion present in the spine and neck elements, which makes the determination of an unique initial position for this dummy rather difficult.

In contrast with the Part 572 dummy, the neck and spine construction of the P3 require an accurate calibration before each test. This calibration procedure, which is described in reference (4) is relatively simple, however, and requires no dynamical tests. Omitting this calibration resulted in rather large high-frequency vibrations in the head accelerations.

Based on this study the following important aspects for future child dummy design should be notified:

- Since the dummy response is very sensitive for the neck and spine properties, particularly the design of the neck and spine dummy segments should be the objective of future research.
- On the one hand the properties of the neck and spine of the P3 dummy are more realistic than those of the Part 572 dummy but this causes on the other hand a lower repeatability of the head and chest accelerations. Special attention should be given to this aspect in future improvements in design,
- In this study a mathematical model of a child was succesfully employed with the objective of analysing differences in dummy response. It is expected that in future dummy design work this model could play a meaningful role for a systematical design optimization.

The experiments in this study were conducted with a child seat with harness. Consequently, the various findings in this paper are not necessary valid for other types of child restraint systems. In a separate study the behaviour of both dummies in other systems will be evaluated.

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