REDUCTION IN SEAT BELT EFFECTIVENESS DUE TO MISUSE

E.G. Janssen, C.G. Huijskens, M.C. Beusenberg
TNO Road-Vehicles Research Institute
Crash Safety Research Centre
Delft, The Netherlands

Abstract

The wearing rate of standard 3-point seat belts by front seat car occupants in the Netherlands is about 70%. Field studies have shown that about 1/3 are used incorrectly. So approximately 50% of the front seat occupants are not or insufficiently protected by their seat belts.
The influence of incorrect use or misuse on the seat belt effectiveness has been studied by the TNO Crash-Safety Research Centre in an extensive research programme. Eight full-scale tests have been performed with a car body mounted on an impact sled. The influence of variations in seat position and belt routing on adult and child dummy responses are studied. The effect of an additional driver airbag system on the dummy loadings is also analyzed in this programme.
The results of this test programme are presented in terms of Ride-Down-Effect (RDE), dummy velocity-displacement curves, dummy contact with the car interior and injury criteria. The injury criteria of the individual body parts are combined into one overall value. Injury probability analysis has been used to evaluate the effect of misuse configurations.
It is concluded that certain misuse configurations extremely reduce seat belt effectiveness. A clear understanding of the type of misuse and the effect on occupant injuries have important implications for the design of protection systems, community actions (e.g. governmental campaigns) and legislation.

INTRODUCTION

Seat belts were introduced some 30 years ago to protect car occupants in a frontal crash. The belt should prevent contact of the occupant with the car interior. Furthermore, the belt should decelerate the occupant optimally, by using the crash deformation of the car and by using the elongation of the belt.
Since June 1975 the wearing of seat belts by front seat occupants in passenger cars is mandatory in the Netherlands. National belt use rates increased from around a 25% level in 1974 to around 50% in 1975. Since then, no steep increase has taken place, despite several public campaigns. Seat belt use has stabilized at around 60% inside built-up areas and around 80% outside built-up areas for the past few years [1]. This is relatively low compared with other European countries like Germany and the United Kingdom.
Besides this low wearing rate, it is know from literature that seat belts are not always worn correctly, which will probably influence their effectiveness in crashes. Often mentioned as incorrect use or misuse of the seat belt system are [2, 3]: excessive slack, a wrong position or routing of the belt, a wrong position of the seat or a wrong body attitude. Appel et al. [2]

found that misuse contributed for 35% to the 'failures' resulting in injuries to occupants involved in a frontal crash. Excessive slack in the shoulderpart and/or lappart of the belt system was frequently observed, however serious injuries were mainly caused by an incorrectly positioned lappart.
Green et al. [3, 4] described several cases of misuse and the resulting injuries. As examples of misuse two cases are mentioned here, one case in which the shoulderpart was positioned under the arm-pit and the other one where the seat back was placed in a sleeping position. Niederer et al. [5] found that misuse strongly influences the effectiveness of seat belts; a large amount of slack considerably increases the overall injury severity.

How many car occupants in the Netherlands are sufficiently protected by seat belts taking into account that the wearing rate is only 70% and among these there could be a considerable number of incorrectly used or even misused belt systems? In order to obtain an insight in this problem, two reseach programmes have been carried out recently in the Netherlands. A field study has been carried out by the SWOV Institute for Road Safety Research, aimed at investigating the frequency of misuse of adult seat belts and child restraint systems (see also [6]). An experimental test programme has been performed by the TNO Crash-Safety Research Centre to study the effect of misuse on the occupant kinematics and injury severity. The effect of an additional driver airbag system was also analyzed in this programma. A second purpose of the study was to obtain high speed films for public campaigns with respect to misuse.

This paper describes the experimental research programme, after a short presentation of the field study.

FIELD STUDY

The methodology of the Dutch field study aimed at investigating the frequency of certain types of misuse of restraint systems and results of this study specificly concerning child restraint systems are described by Schoon et al. [6].
Table 1 shows the results for the front seat car occupants with respect to correct use, incorrect use and misuse of the standard 3-point seat belt. In 35% of all cases the seat belt was worn such that the researchers judged this as misuse. Specific aspects of interest to be judged in this field study were; routing of the belt system (e.g. lappart on abdomen, twisted belt, belt under arm-pit, belt close to neck) and seating position of the occupant (e.g. forward vs. rearward position of the seat, seat back angle).

Table 1 *Correct use, incorrect use and misuse of seat belts by front seat occupants [7].*

	Correct		Incorrect		Misuse		Total	
	n	%	n	%	n	%	n	%
Drivers	122	55	37	17	63	28	222	100
Passengers	64	40	26	16	69	43	159	100
Total	186	49	63	17	132	35	381	100

Every aspect was judged in terms of correct use or not (0 or 1 point) and then weighted by a predefined factor, based on engineering judgement with respect to the probability of serious injuries. The scores were then added up and a final assessment was obtained in terms of correct use, incorrect use or misuse [7]. One aspect or a combination of aspects can therefore result in a total score of 'misuse'.

The frequency of specific aspects found in this field study are:

- shoulderpart under arm-pit (2% of all drivers and 2% of all passengers);
- shoulderpart behind back of occupant (0.5% of all drivers; 1 case);
- shoulderpart on 'arm' (9% of all drivers and 21% of all passengers);
- shoulderpart close to neck (8% of all drivers and 8% of all passengers;
- twisted belt (20% of all drivers and 23% of all passengers);
- excessive slack in belt system (8% of all drivers and 9% of all passengers);
- hippart positioned on abdomen (4% of all drivers and 9% of all passengers);
- large seat back angle (6% of all drivers and 9% of all passengers).
- seat positioned far rearward (9% of all drivers and 17% of all passengers);
- not optimal position of adjustable anchorage point B-pillar (19% of all drivers and 38% of all passengers).

It seems obvious from Table 1 that more drivers than passengers are using the seat belt correctly.

Since more than 1/3 of the front seat occupants in the Netherlands using a seat belt are not using the belt system correctly (in combination with the car seat) and since the wearing rate in the Netherlands for these car occupants is approximately 70%, it can be concluded that more then 50% is insufficiently protected.

The misuse of seat belts if even more stimulated by public advertisements in which a comfort-clip is promoted, which avoids the "tightning" effect of the belt during long trips (see Figure 1). The slack in the shoulderpart is increased by the user and then the clip is clamped on the belt, blocking the function of the pillar-loop and the retractor.

Until 1992, another 'misuse' problem in the Netherlands was the fact that children under the age of 12 years, sitting on the front passenger seat, were allowed to use a standard 3-point adult belt as lapbelt by wearing the shoulderpart behind the back of the child. This was advised by the Dutch Government in favour of a situation where the shoulderpart would penetrate the neck. This and other misuse aspects have been evaluated by TNO in an experimental test programme.

Figure 1 *Example of advertisement for 'comfort-clip'.*

TEST PROGRAMME

Introduction

Three series of sled tests have been performed; one series with correctly used seat belts (called standard tests or C-tests), one series with a misuse configuration (M-tests) and one series with an airbag system installed (A-tests). The test set-up is described below in terms of used vehicle and dummies, as well as seat and restraint position. Table 2 gives a summary of the complete test programme.

Table 2 *Variations in the test programme.*

Testno.	Driver		
	Dummy	**Belt routing**	**Seat position**
C-1	Hybrid II	Correct	Standard
C-2	Hybrid III	Correct	Standard
C-3	TNO-10	Correct	Standard
M-1	Hybrid III	Correct	Rearward
M-2	Hybrid III	Under arm-pit	Standard
M-3	Hybrid III	Behind back dummy	Standard
A-1	Hybrid II	Correct + airbag	Standard
A-2	Hybrid II	No belt + airbag	Standard
	Passenger		
C-1	Hybrid III	Correct	Standard
C-2	Hybrid II	Correct	Standard
C-3	TNO P3/4[2]	Correct + CRS[1]	Rearward
M-1	Hybrid II	Correct	Back angle 40^0
M-2	Hybrid II	Behind back dummy	Standard
M-3	TNO P6[2]	Behind back dummy	Standard

1 Rear ward facing Child Restraint System
2 Child dummy

Vehicle

A reinforced body of a European passenger car was rigidly mounted on a moving barrier (i.e. sled). Figure 2 shows the test set-up. The sled was decelerated using crumple tubes, where the deceleration characteristics of the passenger car in a 56 km/h NCAP test were used as test condition in this programme. Standard interior components, such as seat belts, front seats and steering wheel of the passenger car were used. They were replaced by new ones after each test. In testno. A-1 and A-2 a steering wheel, including an airbag system, and a kneebar from another European passenger car were used. Sled, as well as vehicle body accelerations were measured. In the airbag tests also the steering column accelerations were recorded.
The tests were filmed using 8 high speed film camera's.

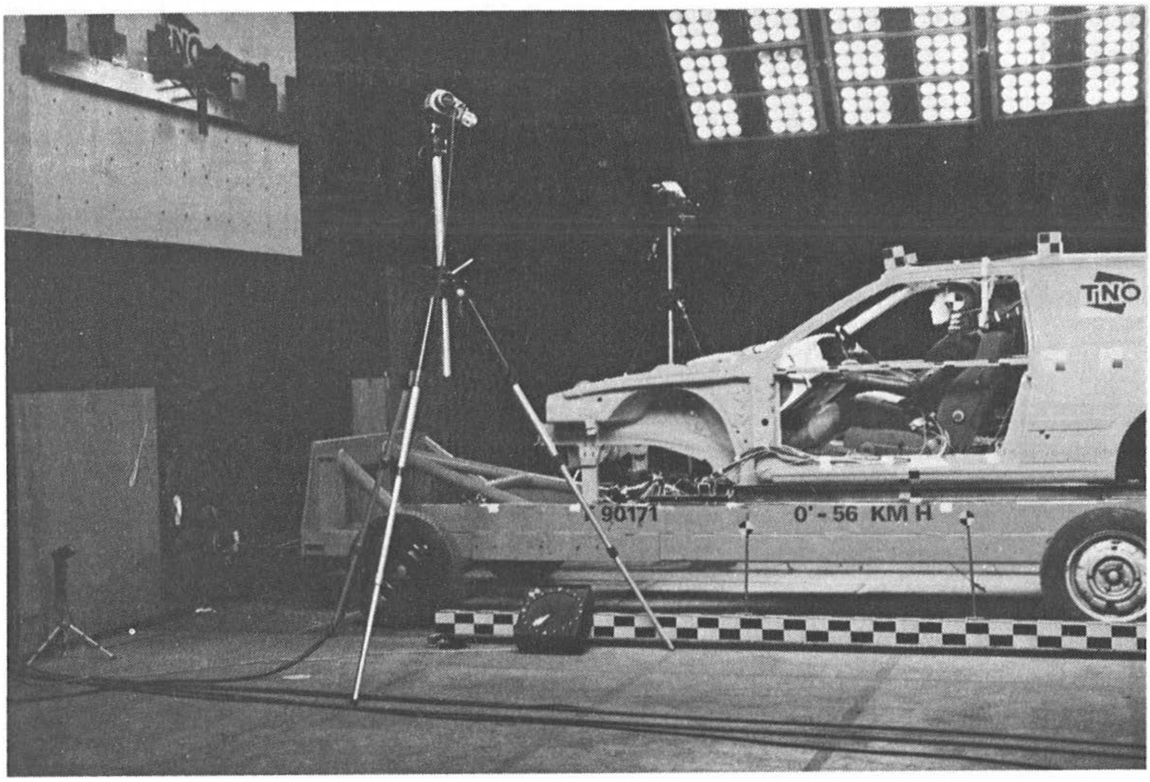

Figure 2 *Test set-up showing car body mounted on impact sled.*

Dummies

Hybrid II and Hybrid III dummies were used as driver and/or passenger in this programme. Head, chest and pelvis accelerations, femur forces, neck forces and moments (only Hybrid III) were recorded.
For comparison reasons the TNO-10 dummy, described in ECE Regulation 16 (seat belts), was used as driver in one test. The TNO P6 and P3/4 child dummies, described in ECE Regulation 44 (child restraint systems) were used as front seat passengers in two tests. Head and chest accelerations were recorded with these three TNO dummies.

Seat position and restraint system

Two types of misuse have been studied:

- a non-optimal seat position creating 'space' between the shoulder and the belt;
- a non-correct routing of the belt by positioning the belt under the arm-pit or behind the back of the dummy.

The driver seat was adjusted in the middle (fore-after) and lowest position (top-down), while the passenger seat was placed in the middle/middle position. In testno. M-1 and C-3 the driver seat, respectively the passenger seat was placed in the most rearward position (see Table 2). The standard seat back angle was 25° for both driver and passenger seat, except in testno. M-1 were the passenger seat back angle was 40°.
In all tests the standard 3-point belt with retractor was used. Belt forces were measured at three locations. In testno. C-3 a rearward-facing child restraint system for ECE group 0 was used as well.

In testno. A-1 and A-2 an additional driver airbag and kneebar were used. In testno. A-2 the belt system was not used. The airbag was externally triggered 10 ms after the impact.
In the A- and C-tests the position of the seat belt was correct. In the M-tests, the routing of the lappart was always correct, while the routing of the shoulderpart was deliberately changed in some tests (see Table 2).

TEST RESULTS

Introduction

The dummy responses are analyzed in terms of kinematics (i.e. motion and velocity) and in terms of injury criteria (including risk). The capability of these parameters to distinguish between correct use and misuse is evaluated. Driver testno. C-3 (TNO-10 dummy) and passenger testno. C-3 (TNO P3/4 dummy), which were performed to compare the results also with that of ECE-R16 (seat belts) and ECE-R44 (child restraint systems) respectively, are not presented here.
The results of the M-series and A-series are always compared with that test of the C-series in which the same dummy type (i.e. Hybrid II or Hybrid III) was used.

Kinematics

Ride-Down-Effect
The belt system should decelerate the occupant smoothly by using the crash deformation path of the car. The so-called Ride-Down-Effect (RDE) has been calculated to assess the amount of the car deceleration shared by the occupant (see also ref.[8]):

$$RDE = (S_v - S_r) \times 100\% / S_v$$

S_v = maximum outer deformation path of car
S_r = deformation path of car up to the time t_r at which the restraint system comes into effect

To determine the Ride-Down-Effect, the resulting thorax deceleration is required, as well as the time function of the car deformation path which can be determined by double integration of the car deceleration (see Figure 3).
To determine the time t_r, at which the retractor has blocked and the slack in the belt has been taken up, a straight line is placed on the rising curve of the resulting thorax acceleration. The line connects the points on the curve representing 25% and 75% of the (first) peak acceleration (see Figure 3). The intersection of the line with the time axis marks the point in time t_r from which the restraint system is assumed to take effect. At this time, the car has already passed through a deformation path of S_r. This path is substracted from the maximum dynamic deformation path and thus describes the percentage of the car deceleration shared by the occupant. According to this calculation RDE=100% means that the occupant is decelerated immediately, without belt slack etcetera, while RDE=0% indicates that the occupant is not decelerated until the maximum dynamic car deformation path has been reached.

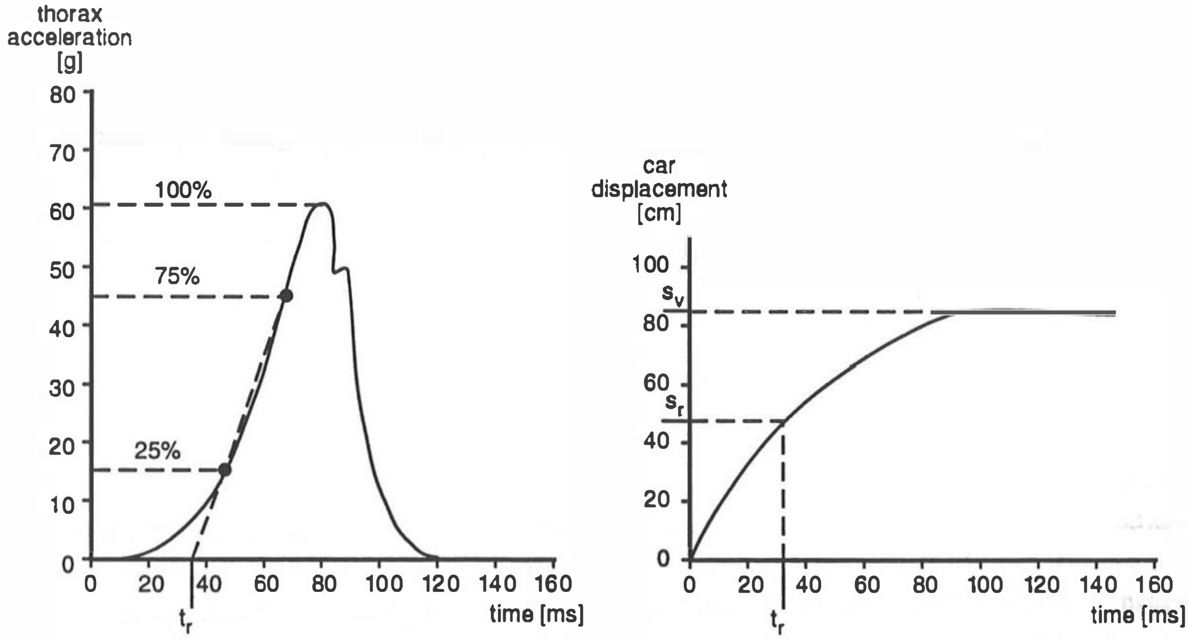

Figure 3 *Resultant thorax acceleration versus time showing the definition of t_r and the car displacement versus time showing the definition of S_r and S_v.*

Table 3 summarizes the calculated RDE values for the tests evaluated here. S_d is the dummy thorax displacement relative to the car at time t_r, calculated from the double integration of the longitudinal thorax acceleration minus S_r. For comparison reasons the RDE calculation of this seat belt system in a standard ECE Regulation 16 test using a Hybrid III dummy is also presented in Table 3. Here the value is somewhat higher than that in the car sled tests with the correctly used belt system (C-series). So an RDE value of 55% obviously indicates a good effectiveness of this belt system.
From Table 3 it seems that the position of the seat and the seat back do not influence RDE, the results of testno. M-1 are similar to that of C-1 and C-2. Positioning of the shoulderpart of the adult belt under the arm-pit (testno. M-2 driver) also appears to have no influence on RDE. However, positioning of the shoulderpart of the belt behind the back of the driver (testno. M-3) or the passenger (testno. M-2) considerably reduces the calculated RDE; from

40% to 20% and from 40% to 8% respectively. The RDE value of the driver is somewhat higher than that of the passenger in this misuse configuration, because the thorax of the driver is partly decelerated by the steering wheel. The 6-year child passenger wearing the belt behind the back shows a relatively low RDE-value.
Introducing an airbag besides wearing the seat belt (testno. A-1) seems not to influence the RDE. However, when the airbag 'replaces' the safety belt (testno. A-2), the RDE drops to 7%. This means that the car is almost stopped when the occupant impacts the airbag, with a relative high impact velocity.

If the time t_r from which the restraint system takes effect is very late, so the RDE-value is low, it can be expected that the forward motion of the thorax relative to the car is large. This is illustrated in Table 3 by the distance S_d. If this displacement is too large, the thorax and/or the head will contact the car-interior, which could lead to serious injuries.

Table 3 *Calculated Ride-Down-Effect RDE.*

Testno.	Driver			Passenger		
	t_r(ms)	S_d(cm)	RDE(%)	t_r(ms)	S_d(cm)	RDE(%)
C-1/C-2	37	5	40	36	5	40
M-1	37	6	40	36	5	40
M-2	35	5	41	69	24	8
M-3	54	13	20	59	19	17
A-1	34	5	41			
A-2	66	27	7			
ECE-R16				14	1	55

Velocity-displacement
Another way of analyzing the kinematics of the car occupants is by looking at the velocity versus displacement curves. Figure 4 illustrates this with a curve for an ECE-R16 test with a Hybrid III dummy. The curves are calculated from the longitudinal sled deceleration and the longitudinal thorax acceleration. The earlier the thorax starts to decelerate the more the thorax uses the car deformation path. The time-points t_r on both curves are connected by a line. The horizontal component of this line represents the relative thorax-to-car displacement S_d and the vertical component represents the relative thorax-to-car velocity. It can be seen from Figure 4 that the relative thorax displacement at time t_r is approximately 1 cm (see also Table 3). The maximum thorax displacement is approximately 21 cm more than the maximum sled displacement. The RDE-value is also given in the sled velocity-displacement curve. The lower the RDE-value, the larger the thorax displacement before the thorax velocity starts to drop. As an example, also a situation without a seat belt is shown in Figure 4.

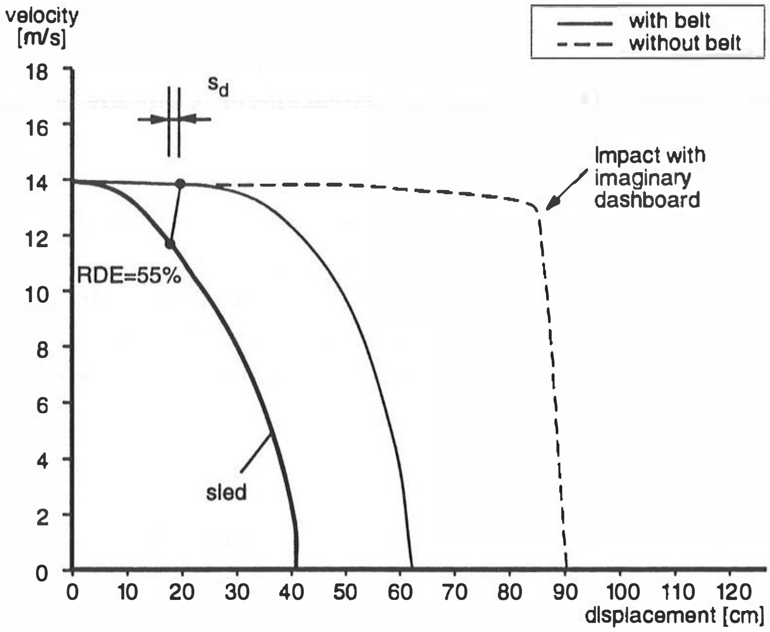

Figure 4 *Velocity versus displacement of sled and Hybrid III thorax in ECE-R16 sled test. An imaginary curve for a dummy without a seat belt impacting a dashboard is also shown.*

Figure 5 shows the velocity-displacement curves for the car-body mounted on the sled and the driver in testnumber C-2, M-1, M-2 and M-3. The t_r-lines and RDE-values are also presented in this figure. From this figure it appears that the seat position (testno. M-1) has practically no influence on the kinematic results.

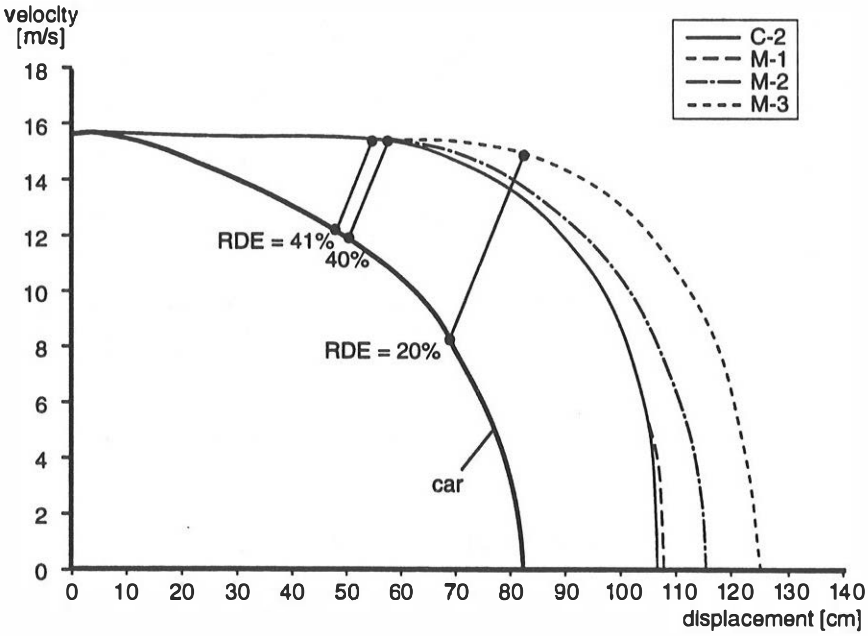

Figure 5 *Velocity versus displacement of car and Hybrid III thorax in the driver testnumbers C-2, M-1, M-2 and M-3.*

With the shoulderpart positioned under the arm-pit (testno. M-2) the curve devides somewhat from the curve with the correctly used seat belt (testno. C-2); the final thorax displacement is approximately 9 cm further. Note that the car displacement is already 50 cm before the belt system becomes active. The relative velocity between car and occupant at that time is approximately 3.5 m/s.
With the seatbelt positioned behind the back of the driver (testno. M-3), the car displacement is already 70 cm and the relative velocity has been increased to 7 m/s, before the thorax starts to decelerate. This deceleration is caused by the lower part of the body, which is stopped by the lappart of the belt and by the knee-to-dashboard impact. The final thorax displacement is some 42 cm more than the car displacement, while the initial distance between thorax and the centre of the steering wheel was 30 cm.

Figure 6 compares the velocity versus displacement curves from the standard test (no. C-1) and the airbag tests A-1 and A-2. It can be seen that an extra airbag system (testno. A-1) does not influence the kinematics of the thorax. However, when the airbag replaces the seat belt system (testno. A-2) the differences are considerable. The car is almost at rest (RDE-value of 7%) before the thorax impacts the airbag. The relative velocity between car and occupant is then very high (i.e. 8.5 m/s).

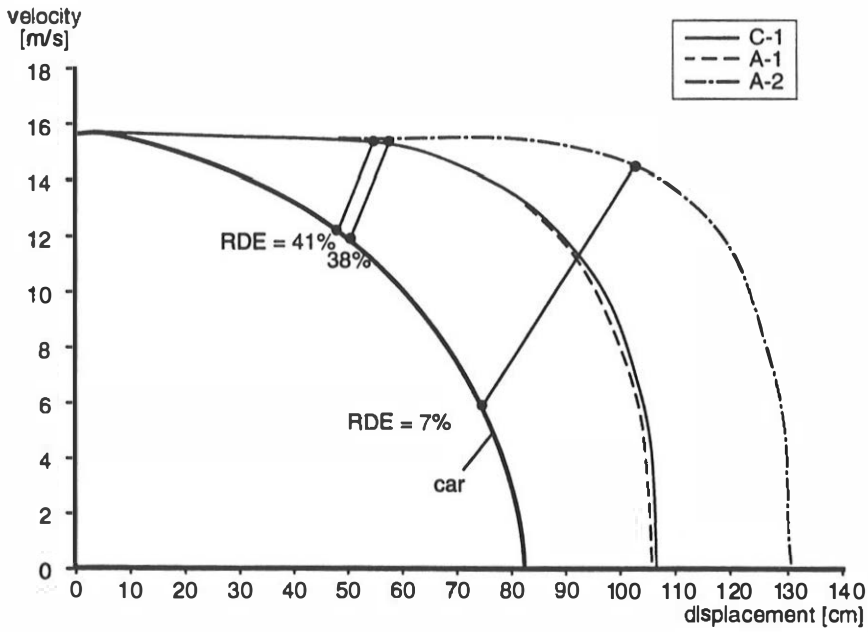

Figure 6 *Velocity versus displacement of car and Hybrid II thorax in the driver testnumbers C-1, A-1 and A-2.*

Figure 7 shows that the seat back angle (testno. M-1) appears to have a slight influence on the velocity-displacement curve of the passenger, compared with the standard test (no. C-2). When the shoulderpart is positioned behind the back of the passenger (testno. M-2), the car is almost at rest (80 cm displacement) before the thorax is decelerated by the lower body. The RDE-value is extremely low (i.e. 7%). The maximum thorax displacement is almost 70 cm more than that of the car, while the initial distance between thorax and dashboard was approximately 60 cm. However, the car displacement is practically linear, while the dummy thorax follows an arc.

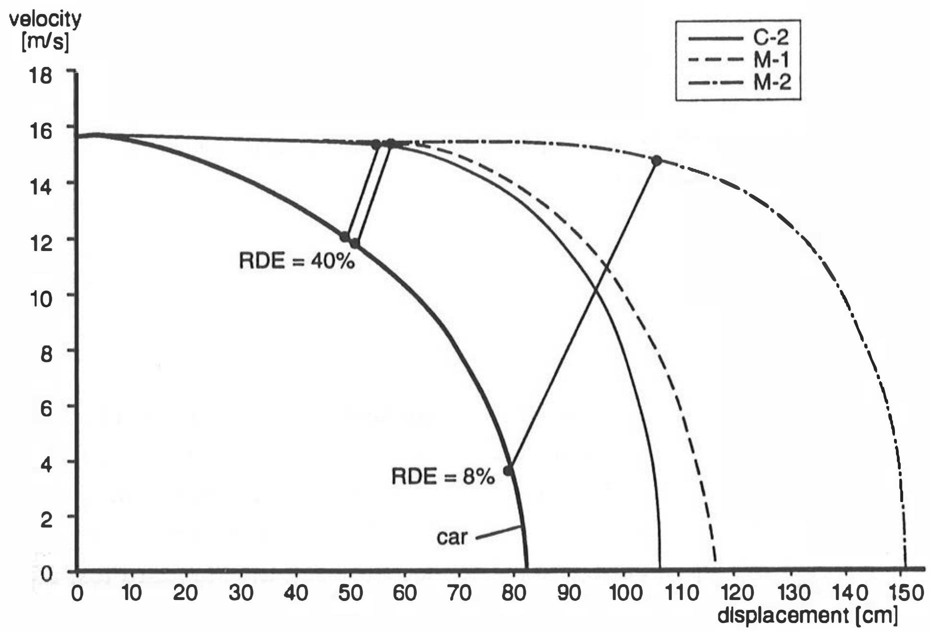

Figure 7 *Velocity versus displacement of car and Hybrid II thorax in the passenger testnumbers C-2, M-1 and M-2.*

Contacts with interior

The relatively large forward displacement of the thorax in some tests, has resulted in contact of the head and/or thorax with the car interior.

With a correctly used seat belt the face of the driver impacts the relatively hard centre of the steering wheel in these 56 km/h sled tests (note: no intrusion of steering column or dashboard occurs). The forehead of the driver impacts the same point on the steering wheel if the seat is positioned rearwards (testno. M-1). With the seat belt under the arm-pit (testno. M-2) the forward displacement of the thorax is larger than that in the standard test (see Figure 5); the thorax impacts the lower ring of the steering wheel. The forward head excursion is also larger; the face impacts the upper ring of the steering wheel slightly before impacting the dashboard behind the steering wheel. With the seat belt positioned behind the back of the driver (testno. M-3), the kinematics even look worse. The lower ring of the steering wheel penetrates the soft abdomen, the thorax impacts the whole steering wheel and the head of the driver is lashed over the steering wheel onto the dashboard. A considerable dynamic deformation of the dashboard can be seen on the high speed films. The initial distance between the head and the upper ring of the steering wheel was 44 cm.

With an additional driver airbag system (testno. A-1), the head contacts the airbag rather than the steering wheel. When the seat belt is not used, but only an airbag system (testno. A-2), the thorax is stopped by the airbag instead of by the belt. The head slides over the airbag and impacts the windscreen.

With a correctly used seat belt, the head of the passenger will not contact the car interior in these 56 km/h sled tests (note: no intrusion of the dashboard occurs). However, the chin im-

pacts the thorax with considerable violence. The forward thorax displacement is slightly larger than that of the standard test, when the passenger seat back is inclined backwards (see Figure 7). However, the head still does not contact the car interior. With the seat belt positioned behind the back of the passenger (testno. M-2) the forward thorax displacement is very large (see Figure 7) and the head impacts the dashboard. The initial distance between head and dashboard was 71 cm.
Even the head of the 6-year child dummy impacts the dashboard, when the shoulderpart of the belt system is worn behind the back.

Injury criteria

Maximum values
Table 4 summarizes the dummy results for the standard FMVSS 208 criteria and some additional measurements. The results for the neck forces and moments are not presented here, since they seem to vary too much because of slight differences in impact location.
Since a variation of ± 10% can be expected for each dummy response, an influence of a misuse parameter is considered present if the difference between the standard test and the misuse test is more than 20%.

Table 4 *Maximum dummy responses.*

	Testnumber						
Dummy responses	**C-1**	**C-2**	**M-1**	**M-2**	**M-3**	**A-1**	**A-2**
Driver head							
HIC	991	1595	1024	724	2003	193	673
3 ms max accel [g]	93	114	84	71	120	42	59
Driver thorax							
3 ms max accel [g]	50	52	49	42	61	51	71
max deflection [mm]	--	42	35	54	28	--	--
Driver pelvis							
3 ms max accel [g]	60	56	53	57	70	60	62
Driver femur							
max force left [kN]	1.5	1.9	4.4	1.3	2.5	2.9	7.6
max force right[kN]	1.2	0.7	1.7	1.9	2.9	3.8	5.6
Passenger head							
HIC	1246	887	1328	6120	NA 1)		
3 ms max accel [g]	87	72	85	213	166		
Passenger thorax							
3 ms max accel [g]	48	45	38	92	49		
max deflection [mm]	43	--	--	--	--		
Passenger pelvis							
3 ms max accel [g]	64	58	60	65	--		
Passenger femur							
max force left [kN]	1.9	2.0	2.8	2.0	--		
max force right[kN]	1.0	1.7	2.2	2.1	--		

1) Not available

Figure 8 shows the 3 ms maximum resultant head acceleration for the driver in testnumbers C-2 (correct use), M-1 (seat rearward), M-2 (belt under arm-pit) and M-3 (belt behind back). The results of the M-testseries are presented as percentage of the C-2 result, which is defined as 100%. It can be seen that the results of testno. M-1 and M-2 are considerable lower than 100%, while the M-3 result is similar to that of testno. C-2. The HIC-values presented in Table 4 show a similar trend; for testno. M-1 and M-2 lower values are obtained and the HIC-value in testno. M-3 is significantly higher.
Figure 9 shows the results for the passenger head in testnumbers M-1 (angled seat back) and M-2 (belt behind back) as percentage of the result in testno. C-2 (correct use). The 3 ms maximum acceleration in testno. M-1 is within the ± 20% corridor, while the M-2 result is extremely higher than that of the standard test. The HIC-values presented in Table 4 indicate a significantly higher result in testno. M-1 and M-2 compared with the standard test.
The head injury criteria seem to indicate extreme misuse of the belt system, but not all misuse configurations can be assessed by looking at the head injury criteria. For some driver misuse configurations even a lower value is shown.

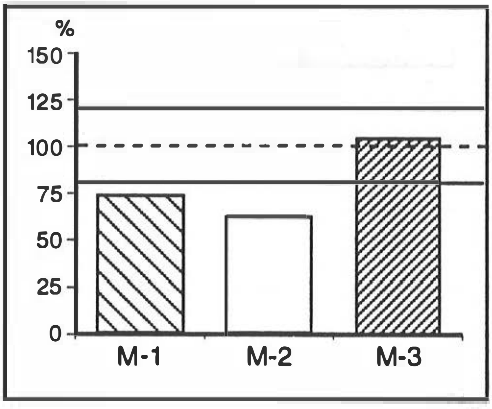

Figure 8
3ms maximum resultant head acceleration for the driver testnumbers M-1, M-2 and M-3 as percentage of the C-2 result

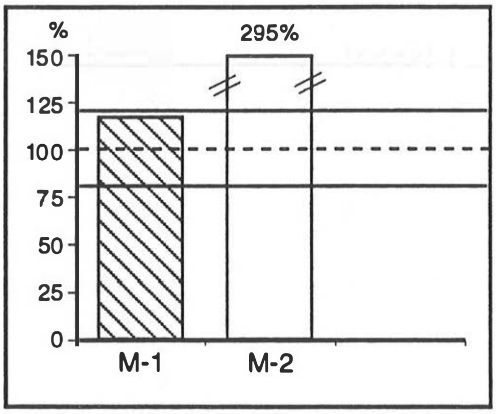

Figure 9
3ms maximum resultant head acceleration for the passenger testnumbers M-1 and M-2 as percentage of the C-2 result.

Figure 10 shows the 3 ms maximum resultant chest acceleration of the driver in the standard test and the 3 misuse tests. All results are within the ± 20% corridor. The two misuse configurations "belt under arm-pit" (testno. M-2) and "belt behind back" (testno. M-3) indicate a different trend; a lower respectively a higher 3ms maximum chest acceleration compared with the standard test. The maximum chest deflections, shown in Figure 11, indicate an opposite trend; a much higher deflection in testno. M-2 and a much lower in testno. M-3.
Figure 12 shows the 3ms maximum resultant chest acceleration for the passenger in the standard test and 2 misuse tests. The result of testno. M-1 is within the ± 20% corridor, while the result for testno. M-2 (belt behind back) is considerably higher.
Extreme misuse configurations are seen by the chest injury criteria, however with different outputs. Sometimes a lower maximum is found for one criterion, while another shows a higher value for that specific test.

The 3 ms maximum pelvis accelerations are not strongly influenced by the misuse configurations tested here (see Table 4). Table 4 shows that the femur forces are to some extend influenced by the seat position, however they are far below the FMVSS 208 tolerance criterion of 10 kN.

Figure 13 shows that the 3 ms maximum resultant head acceleration in the two airbag tests is much lower than that of the standard test (C-1). The HIC-values presented in Table 4 indicate the same trend. Figure 14 shows that the 3 ms maximum resultant chest acceleration is not influenced by the additional airbag (testno. A-1), while this parameter is much higher for the test with an airbag and without seat belts (testno. A-2). The reinforced dashboard with kneebar in testno. A-1 shows higher femur forces than in the standard test, and much higher forces in the test without seat belt system (testno. A-2).

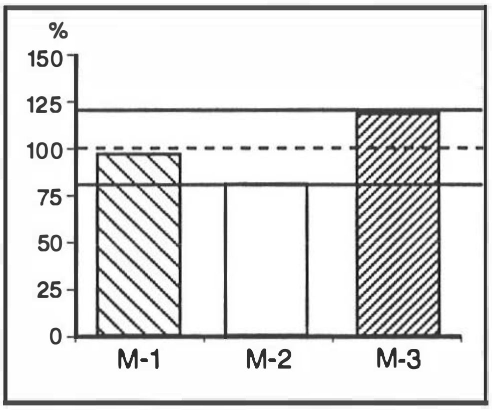

Figure 10
3ms maximum resultant chest acceleration for the driver testnumbers M-1, M-2 and M-3 as percentage of the C-2 result.

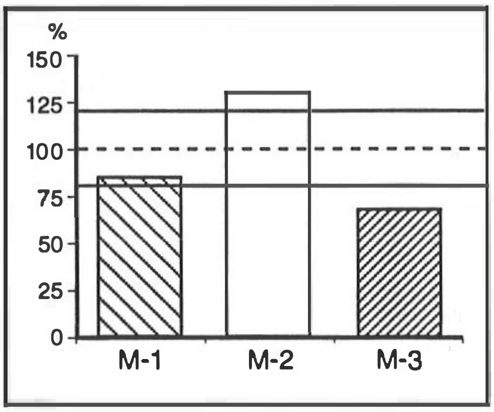

Figure 11
Maximum chest deflections for the driver testnumbers M-1, M-2 and M-3 as percentage of the C-2 result.

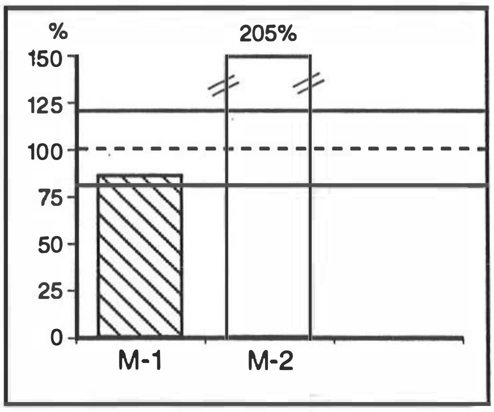

Figure 12
3ms maximum resultant chest acceleration for the passenger testnumbers M-1 and M-2 as percentage of the C-2 result.

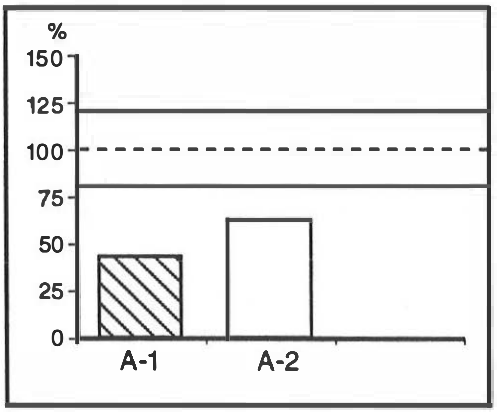

Figure 13
3ms maximum resultant head acceleration for the driver testnumbers A-1 and A-2 as percentage of the C-1 result.

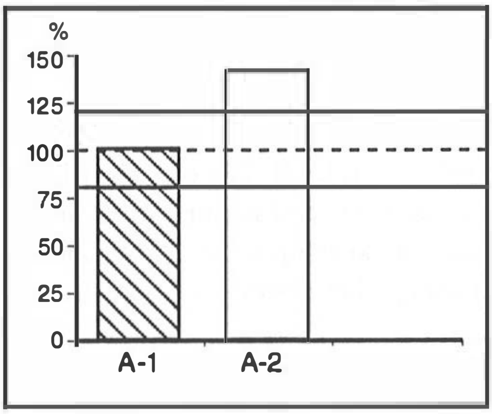

Figure 14 *3ms maximum resultant chest acceleration for the driver testnumbers A-1 and A-2 as percentage of the C-1 result.*

Single parameter

In [9] a method is described to calculate a single value for overall injury risk by normalizing each response by its tolerance value and then multiply it by a weighting factor. This factor is 60% for the head response (HIC= 1000), 35% for the chest (A_{3ms}= 60 g) and 5% for the lower extremities (F= 10 kN) in terms of FMVSS 208 citeria. So the injury criteria can be combined in a single parameter to assess overall safety performance called IC_{208}:

$$IC_{208} = 0.60*[HIC/1000] + 0.35*[A_{3ms}/60g] + (0.05/2)*[(F_l/10kN) + (F_r/10kN)]$$

Table 5 shows the results of this calculation for the three test series. It appears that the driver misuse configurations M-1 and M-2 show a decreasing IC_{208}-value compared to the standard test. This is caused by the lower HIC-values in these tests. Only testno. M-3 (belt behind back) indicates a higher injury risk. For the passenger the misuse configurations show an increasing IC_{208}-value, especially when the belt is positioned behind the back (testno. M-2). With an additional driver airbag (testno. A-1) the HIC-value is decreased considerably, resulting in a 50% lower IC_{208}-value. However, when the belt system is not used (testno. A-2), the airbag alone indicates the same risk as in the standard test.

Table 5 *Combined injury criteria IC_{208}.*

	Testnumber						
Occupant	**C-1**	**C-2**	**M-1**	**M-2**	**M-3**	**A-1**	**A-2**
Driver	0.89	1.27	0.92	0.69	1.57	0.43	0.85
Passenger	1.04	0.80	1.03	4.22			

Probability function

A more preferred approach for assessing occupant protection involves interpreting dummy responses using an injury risk function based on probability analysis of biomechanical data [9].

The probability function is non-linear, with a strongly increasing injury risk above the tolerance level:

$$p(x) = [1 + \exp(\alpha - \beta x)]^{-1}$$

This function relates the probability of injury to a dummy response x using two parameters α and ß, which are determined from the best fit to approximate biomechanical data. Table 6 presents these parameters according to ref. [9]. The overall risk of injury is determined by the sum of the individual risks of head, chest and femurs. Since individual risk varies from zero to one, the overall risk of injury can exceed p = 100%, indicating multiple injuries or causes of death. Table 7 summarizes the calculated overall risk for the three test series.

The probability of serious injuries (i.e. AIS 4+ for head and chest, AIS 3+ for femurs) for the driver in the standard test (C-2) is large (77%) due to the severe head to mid-steering wheel impact. The M-series shows the same trend as presented above for the IC-value; decreasing for testno. M-1 and M-2, increasing (above 100%) for testno. M-3.
The standard test for the passenger (testno. C-2) appears to have a much lower probability of serious injuries (21%) compared with that of the standard driver test. The passenger misuse configurations show a higher probability of serious injuries; 47% and 170% for testno. M-1 and M-2 respectively.

The test with the additional airbag system (testno. A-1) indicates a 50% lower probability of serious injuries compared with the test using seat belts only (testno. C-1). When the seat belts are not used, the airbag alone is not able to keep p(x) at the same level as in the standard test; the injury risk is much higher (see Table 7).

Table 6 *Parameters for injury risk function [9].*

Body region	Parameters	
	α	β
Head	5.02	0.00351
Chest	5.55	0.0693
Femurs	7.59	0.660

Table 7 *Injury risk using probability function.*

Occupant	Testnumber						
	C-1	C-2	M-1	M-2	M-3	A-1	A-2
Driver	0.29	0.77	0.31	0.15	1.10	0.14	0.51
Passenger	0.44	0.21	0.47	1.70			

DISCUSSION AND CONCLUSIONS

Car seat belt use in the Netherlands has stabilized at around 60% inside built-up areas and around 80% outside built-up areas, despite several mass public campaigns. A recent field study has shown that 35% of the car drivers and front seat passengers wearing a seat belt appear to 'misuse' the belt system. This means that more than 50% of the front seat occupants in the Netherlands are not or insufficiently protected by the seat belt. Since the misuse frequency of child restraint systems is even 70% [6], public campaigns should focus more on the correct use of restraint systems. Furthermore current laws should be extended by an improved description of 'wearing the seat belt' and by forbidding the use of 'comfort-clips'.

The TNO Crash-Safety Research Centre has conducted a series of sled tests to evaluate the influence of certain type of misuse configurations on the dummy kinematics and injury criteria. Two types of misuse have been studied:

- a non-optimal seat position creating 'space' between the shoulder and the belt;
- a non-correct routing of the belt by positioning it under the arm-pit or behind the back of the dummy.

In the first type, seen in 15% of the cases for drivers and in 26% of the cases for passengers [7], the upper torso is not immediately restrained by the belt. The amount of the car deceleration shared by the occupant is called the Ride-Down-Effect (RDE). It appears that the RDE in these 56 km/h sled tests is similar for correctly used seat belts and misuse of the first type (i.e. RDE=40%). So RDE can not differentiate between correctly used belt systems and incorrectly used belt systems.
The second type of misuse is seen in approximately 2% of the cases for drivers as well as passengers [7]. The RDE seems to decrease considerably (i.e. from 40% to 8-20%) when the shoulderpart of the belt is positioned behind the back of the dummy. RDE appears not to be influenced when the shoulderpart is worn under the arm-pit, obviously a 'quick' deceleration of the upper torso is still present. However, analysis of the high-speed films have indicated that this misuse configuration can result in severe head-to-dashboard impacts. It seems that RDE can only indicate very severe misuse configurations, like wearing the shoulderpart behind the back.

In [9] a so-called Restraint Quotient is presented, not based on relative displacement like RDE, but on the ratio between relative velocity of the occupant and maximum velocity change of the car. This ratio has not been calculated here, but the kinematics of the occupants were studied by analysis of velocity-displacement curves. It appears that large differences between car and occupant can be found with respect to displacement and velocity, especially for the misuse configurations of the second type. This means that the effectiveness of the belt system, smoothly decelerating the occupant by effectively using the car's crash zone, is reduced. The second function of the belt system, avoiding occupant contact with the car interior, was also analyzed. Extreme head impact locations can be seen in the tests with the shoulderpart of the belt under the arm-pit or behind the back of the driver. In these tests also chest-to-steering wheel impacts occured. In the passenger tests head-to-dashboard impacts occured in the tests where the belt was positioned behind the back of the adult or 6-year child dummy. So analysis of the motion of occupants and the (possible) impact locations with the car interior can indicate gross misuse configurations. It should be noted here that since April

1992 in the Netherlands children under the age of 12 years are not allowed to sit on the front seat without a child restraint system. Children between 3 and 12 years are still allowed to use the 3-point adult belt as lapbelt, but only on the rear seats and only if no child restraint system is available.
Analysis of the injury severity in this test programme is to some extend influenced by the limited number of tests, and especially of repeated tests. However, some general conclusions are given here. The HIC is strongly influenced by the stiffness of the impact location and could show a low value in a misuse configuration. When no head impacts occurs, for instance in 'slight' misuse configurations, HIC can not be used. The chest injury criteria (i.e. 3ms maximum acceleration and maximum deflection) sometimes show an opposite trend; a low value for one parameter and a high for the other. Furthermore, sometimes lower values are found in a misuse configuration compared with the correct use test.
Combination of the injury criteria in a single parameter shows good results for the passenger tests; higher values in misuse configurations. The results of this calculation for the driver tests appear to be too much influenced by the HIC-value, which depends too much on 'coincidental' head impacts. Similar results are found when the injury probability is calculated. However, a considerable difference was found between the combined criteria calculation and the injury probability calculation in the airbag only test; a similar value respectively a much higher risk compared with the standard belt test.
An important disadvantage in the use of injury criteria and injury risk functions is the limited instrumentation available in the current frontal dummies. The Hybrid III dummy offers more possibilities in this respect than the Hybrid II dummy. Comparison of the 3 ms maximum accelerations of both dummies as driver and passenger in the standard tests C-1 and C-2, shows that the thorax and pelvis responses are more or less identical (i.e. 4-11% differences). The 3 ms maximum head accelerations of the Hybrid III are 20-23% higher and the HIC is 40-61% higher than that of the Hybrid II dummy in similar tests.

Analysis of the kinematics and injury criteria of the driver and passenger dummies in these 56 km/h sled tests, showed that extreme misuse of the 3-point seat belt can significantly reduce the effectiveness of the belt system. Not all misuse configurations could be well identified. Therefore more sophisticated dummies and analysis methods seem necessary.
Several technical solutions can avoid or decrease (the effect of) misuse of seat belts, for instance adjustable anchorage points, integrated belt systems, pretensioners and automatic restraint systems. Airbags can reduce the severity of the head-to-steering wheel impact in a severe crash with a correctly used belt system, but also in a moderate crash with an incorrectly used belt system. The current research programme has also shown that an airbag should not be used instead of the 3-point seat belt, but in combination with this system.

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