BENEFITS OF A 3+2 POINT BELT SYSTEM AND AN INBOARD TORSO SIDE SUPPORT IN FRONTAL, FAR-SIDE AND ROLLOVER CRASHES

Ola Bostrom
Yngve Haland
Autoliv Research
Sweden
Paper No. 451

ABSTRACT

3-point belted occupants are still being injured in numerous crashes. In frontal collisions this is partly explained by the range of hard tissue tolerance amongst car occupants. In side collisions occupants on the far side of the intrusion are mainly restrained by the lap part of the 3-point belt, with an associated high risk of sustaining a severe head injury. During a rollover crash the 3-point belt cannot fully prevent harmful head impacts.

In this study an additional 2-point belt (single handed optional operation) is combined with an inboard torso side support. The idea is simply to distribute the belt load on more anatomical structures (bones) as well as constituting a non-injurious inboard and upward restraint. The inboard side support prevents a direct loading by the 2-point belt to the cervical spine in far-side collisions. It also supports the torso when the 2-point belt is not buckled.

To prove if this design measure is advantageous, frontal, far side and rollover tests were performed. Current standard crash test dummies lack appropriate biofidelity when assessing sophisticated enhancements of standard safety restraints. Therefore the Thor dummy with a set of modifications from the BioSID were used in the tests.

The results showed a considerable reduction of chest deflection in the frontal crash tests, head horizontal motion in the far side tests and head upward motion in the rollover tests. To conclude, an additional 2-point belt, in conjunction with, a 3-point belt and inboard torso side support offer a considerably increased protection in various crash situations without any negative consequences.

INTRODUCTION

The 3-point belt, standard equipment in almost all cars, has been one of the most cost effective life and suffer saving cure during the last decades. One reason for this success, apart from being a legal requirement, is the combination of user friendliness and minimal constriction of the occupant. Additional features such as belt load limiters and pretensioners as well as additional restraints like frontal airbags have been introduced to enhance the effectiveness of the 3-point belt. In side impacts, torso and head airbags have been introduced and shown in crash simulations to offer a great benefit for the near struck side occupant (Pilhall et al. 1994, Håland and Pipkorn 1996, Brambilla et al. 1998, Bohman et al. 1998). Nevertheless, manifested in the about 50% fatal-protective effectiveness (see for example Viano and Arepally 1990), the standard 3-point belt plus the existing airbag systems possess a few principal shortcomings, or potentials of improvements. To begin with the occupant easily slips out of the shoulder part of the belt in side impacts and in rollovers. Therefore the 3-point belt is less effective in restraining in the inboard and upward directions (Mackay et al. 1991, Ward et al. 2001, Parenteau et al. 2001, Digges and Dalmotas 2001, Fildes et al. 2002). Not surprisingly, rollover and far side impacts are among the main causes for 3-point belted occupants to sustain a severe head injury (Fildes et al. 1994, Thomas and Frampton 1999, Parenteau and Shah 2000, Digges and Dalmotas 2001). In frontal impacts, another shortcoming is the fact that the 3-point belt load on the chest is distributed over only half of the ribs and one of the clavicles. The standard 3-point belt distribution of load may be sufficient for today's average car occupant and today's legislative and consumer crash-test severity levels, however, this may not be the case in the future. The maximum chest deformation required to generate rib fractures decrease with age (Kent 2002) and the average age of car occupants is increasing (US Census Bureau 2000). Also, the level of crash severity, where non-intrusion into the occupant compartment as well as survivability is expected, is increasing (Edwards et al. 2001). To conclude, great amounts of human suffering and societal costs would be saved if: compared to today's design of bag and belt systems a) the head relative to vehicle displacement could be reduced in far-side and rollover crashes so that the head is prevented from violently impacting with the inner roof and the opposite side of the vehicle interior and b) the belt load could be distributed over all ribs and both clavicles in frontal crashes, thereby reducing the maximum rib/clavicle loads.

A natural evolution of the standard 3-point belt is to incorporate another fixation point. Today there are at least two types of 4-point belts (centre buckle

V4 belt and 3+2 belt). As described by Ford (Automotive News 2001), the centre buckle V4 belt is shaped as a V worn over the shoulders like backpack straps after the occupant is in the seat. A potential drawback with such a belt system is that the belt forces from the shoulder parts may cause the lap part of the belt to be lifted, thereby enabling the pelvis to slip under the lap belt in a crash. With a 3-point belt the situation is the opposite. The shoulder belt part tightens the lap belt part. The V shaped belt system seems to require the belt to be fully integrated with the seat. A two-hand operation to buckle up is needed. A way to overcome the sub-marining problem, although not so user-friendly, is the inclusion of a fifth point between the legs, a belt system widely used in car racing. Another type of 4-point belt, presented by Saab (Teknikens Värld 2001), hereafter called a 3+2 belt system, is a standard 3-point belt with a supplementary 2-point belt build into the seat (the lower endpoints of the two belts are located close to each other). The 2-point belt can not be buckled up unless the 3-point belt is buckled up first. This type of belt system has also been presented in the rear seat of a Volvo concept car (Automotive News 2001).

Although the standard frontal and side impact dummies HIII and BioSID/EuroSID have successfully been used in designing today's restraint systems in frontal and near side impacts, they are not necessarily effective, when it comes to evaluating the benefit of an extra belt. The HIII dummy was originally developed for evaluating blunt impacts such as the interaction with the steering wheel (Kroell et al. 1974, Kent 2002), although it has been used in the past years in legislative and consumer tests evaluating the 3-point belt and frontal airbag systems. In order to perform a more biofidelic evaluation, NHTSA initiated the development of the Thor (Test device for Human Occupant Restraint) frontal impact dummy. Compared to the HIII, the Thor has a more flexible spine, a human geometry-like rib cage, and a pelvis flesh allowing a full range of motion at the hip joint (Rangarajan et al. 1998). The possible benefit of off-loading the ribcage by allowing both clavicles to take a critical part of the load should be more appropriate with Thor compared to the HIII dummy (Kent 2002b).

Far side collision and rollover occupant protection has not yet been addressed to any great extent in safety initiatives by governments or vehicle manufactures around the world. Thus no far side dummy nor rollover dummy exist. In far side crash simulations it has been shown by Fildes et al. (2002) that the BioSID and the EuroSID, in contrary to a PMHS (Post Mortem Human Subject), had a great benefit of a standard 3-point belt. Yet, according to real life crash analysis by Frampton et al. (1998) and Augenstein et al. (2000) the benefit in far side impacts of a standard 3-point belt is low. The reason for this discrepancy was the lap belt's ability to establish a non-biofidelic torque on the Euro/BioSID's spine, which was resisting bending about lumbar fore/aft axis. In an ongoing research project between GM Holden, Monash University Accident Research Centre and Autoliv Research a set of modifications to the BioSID has been developed in order to faciliate effective measurement of occupant response in far side testing (Fildes et al. 2003). These modifications enable the BioSID's spine to shear, bend and elongate, which makes the modified BioSID also more suitable for rollover testing, at least compared to a HIII dummy.

In this paper a 3+2-belt system for a front seat occupant is proposed and evaluated. The supplementary 2-point belt-in-seat was used together with an inflatable inboard torso side-support (SS). The reason for the side support was twofold. Namely to reduce the effect of direct belt load to the occupant's neck in a far side impact, see Kallieris and Schmidt (1990), and to constitute a far side contingency countermeasure, when the 2-point belt is not buckled up.

The aim of this paper is to evaluate the benefit of the proposed 3+2-point belt system and an inboard torso side-support by means of mechanical simulation of frontal impacts (US-NCAP pulse), far side collisions (3 and 2 o' clock) and soil tripped rollovers (with the dummy on the far side). The dummies used were the frontal dummies Thor and HIII and the side impact dummy BioSID equipped with a modification set.

Figure 1.
The 3+2 point belt system and an inboard torso side support (inflated bag) implemented in a car.

METHOD

The method section is divided into three sub sections: restraint system, dummy and test set up.

Restraint system

For the three crash situations, (frontal, far side and rollover), mechanical simulations were performed with and without an extra 2-point belt and with and without an inflatable torso side support. In Table 1, the restraint equipment and dummy type are listed for each test. In the Thor 2-point frontal tests (Tests 1 and 2 according to Table 1), the 2-point retractor was mounted at an extra inboard pillar whereas in the rest of the tests, the 2-point belt retractor and the side support were integrated into a module attached on the inboard upper side of the backrest, see Figure 1. The side support consists of a bag of 3 litres in volume and a small attachment support for the bag. The side support bag in the far side tests, and the frontal driver airbag in the frontal impact tests were inflated by helium gas using an "inflator simulator" (2 bar gauge pressure for the far side support and 0.4 bar for the frontal bag). In the rollover tests the side support was inflated by compressed air prior and during the tests. The 3-point belt had a 5.5 kN load limiting level (measured at the dummy's shoulder) and was retractor pretensioned in all tests but the far side 3 o'clock reference test (Test 4). The 2-p belt had a 2 kN load limiting level and was retractor pretensioned in the frontal and rollover tests and buckle pretensioned in the far side impact tests. (The change to a buckle pretensioner was merely done to get the 2-point belt and the inboard side support module more compact.)

Dummy

In the frontal tests the Thor dummy was used in the comparison of the 3-point belt and the 3+2-point belt system (Tests 1 and 2). The HIII dummy was used in Test 3, a test with the objective to evaluate seat deformation due to the loads transmitted by the 2-point belt into the seat.

In the far side tests the BioSID with a set of modifications was used. The set consists of a spring lumbar spine able to shear, bend and elongate and a steel plate shoulder enabling a direct belt load to the neck in far side tests and a consistent belt-load-path during rollover tests, see Figure 2 a) and b). For a more comprehensive description as well as motivation and suitability see Fildes et al (2003). The BioSID was right hand instrumented. Apart from the standard equipment the dummy was instrumented with lower and upper neck load cells as well as a head z-axis angular velocity sensor.

In the rollover tests, the modified BioSID was also used due to its new spine's ability to shear, bend and especially elongate (max 70 mm). In addition to the modification set, the BioSID was equipped with a wet suit and a plastic board to enable a realistic abdomen-belt interaction, that is to avoid the belt being caught, when the spine is elongated, see Figure 2c).

Table 1
Restraints used and dummy list for the performed tests

Test	Dummy	3p-belt	2p-belt	Side support	Frontal airbag
Frontal					
1	**Thor**	**X**			**X**
2	**Thor**	**X**	**X******		**X**
3	**HIII**	**X**	**X**		
3 o'clock					
4	**BioSID***	**X*****			
5	**BioSID***	**X**	**X**		
6	**BioSID***	**X**	**X**	**X**	
7	**BioSID***	**X**		**X**	
2 o'clock					
8	**BioSID***	**X**			
9	**BioSID***	**X**	**X**	**X**	
10	**BioSID***	**X**		**X**	
Rollover					
11	**BioSID****	**X**			
12	**BioSID****	**X**	**X**		
13	**BioSID****	**X**	**X**	**X**	
14	**BioSID****	**X**		**X**	

*with modification set, **with modification set plus wet suit,
***no pretensioner, ****inboard pillar mounted

a) b) c)

Figure 2.
a)The spring lumbar spring spine unit and the shoulder plate mounted on to the BioSID's torso.
b) Detailed view of the spring spine unit; the wires obstructs an elongation exceeding 70 mm.
c) The BioSID (seated in the rollover rig) with the plastic board and the wet suit (partly undressed).

Test set up

The test set ups and crash pulses for each test configuration are described in the following sub sections frontal impact, far side impact and rollover.

Frontal impact - In Tests 1 and 2, a buck with the same geometry as a Ford Taurus model year 91 was used. The dummy was seated at the driver's position in front of a steering wheel. The crash pulse, see Figure 3, represents a US-NCAP crash pulse for this car model. In Test 3 the same crash pulse was used although neither buck nor airbag were used. The purpose of this test was only to see if the standard seat used in the test series (a Volvo S80 front seat) could withstand the forces (2 kN) transmitted by the 2-point belt into the seat according to the far side and rollover test configurations (Figure 1).

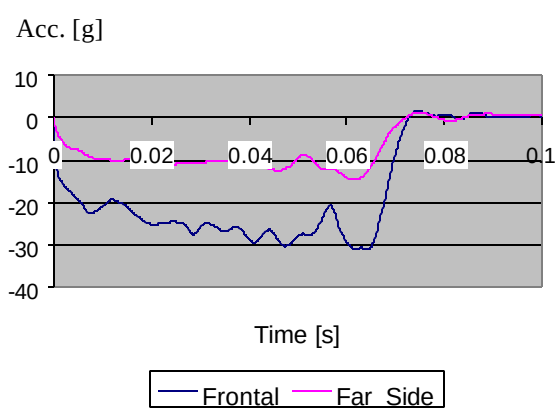

Figure 3.
The crash pulses used in the frontal and far side crash simulations.

Far side impact– The crash pulse used (Δv=24 km/h, 10g), see Figure 3, and corresponding amount of intrusion (about 300 mm) represented a typical example of an injurious far-side collision (Frampton et al. 1998, Digges and Dalmotas 2001, Fildes et al 2002). The feet and knees were restrained from moving inboard by a schematic rigid structure (padded for the knees), see Figure 4. Compare with the sled test method developed by Bostrom et al. (2002), where an already intruded car-body (exposed for the corresponding full-scale side impact) was used. The far side tests were performed for two directions of the seat versus the sled. First, with the seat transversally mounted on the sled, simulating a 3 o'clock far side impact for a driver in a left hand steered car. Secondly, with the seat mounted at an angle of 60 degrees versus the sled direction simulating a 2 o'clock impact. In the 3 o'clock reference test, Test 4, a rigid structure

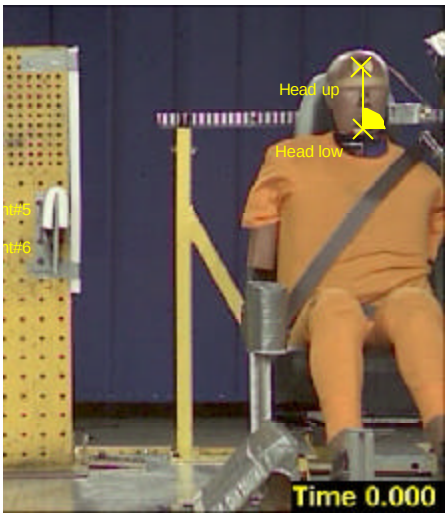

Figure 4.
The front view of the far side test set up at time zero of Test 4. The rigid (padded) structures simulates the foot well and the intruded B-pillar.

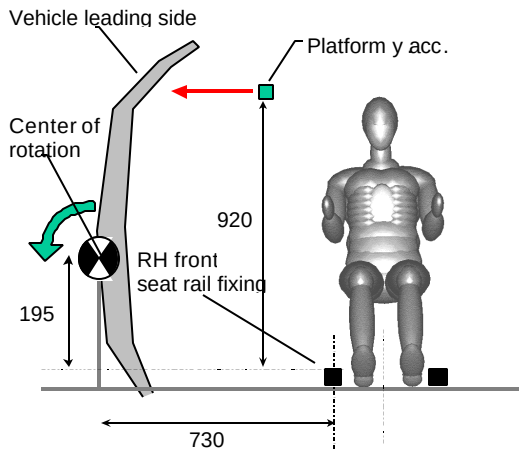

Figure 5
The geometry of the centre of rotation and dummy seat in the rollover rig.

padded with 25 mm Ethafoam 400 was installed 685 mm from the centre of the dummy simulating a simplification of the intruded B-pillar and belt-line, see Figure 4. The choice of distance between the centre of the dummy and the padded rigid structure corresponds approximately to a far side intrusion in the order of 300 mm of a mid-size passenger car.

Rollover - According to Parenteau and Shah (2000) using NASS-CDS data for years 1992 to 1996, the most frequent injurious rollover event for belted occupants was a tripped rollover with a far side occupant (on the non-leading side). In another study (Parenteau et al. 2001) it was found that the risk of AIS3+ injuries to the head for belted/non-ejected far side occupants was higher than for near side occupants. Therefore, a soil tripped rollover with a far side occupant was chosen in the present study to evaluate the benefit of the 3+2 point belt and inboard side support system. The test set up consisted of a steel construction, a platform simulating the compartment of a car able to translate laterally and rotate with a fix rotation axis. This rotation axis, see Figure 5, was a compromise of the true rotation axis, which in a soil tripped rollover in the simplified case moves from a location around the tires of the leading side in the tripping phase to the centre of mass in the airborne phase. The seat for the dummy simulated a far side position. The outboard (car) belt line (side-window sill) was simulated with a steel bar. No window or similar was present, see Figure 2c). The buck was accelerated with a low g-level, and at a speed of 36 km/h the buck was decelerated and rotated until a stop at 160 degrees, which simulated a car-to-ground impact phase. See Figure 6 for the lateral velocity and acceleration, and the rotational angle and angular velocity versus time. Neither roof crush nor dummy-to-roof contact was simulated. Instead the head position relative to the platform was measured during the rollover event by the length and direction of a wire from the platform to the head, see Figure 1 in the appendix. The Advanced Engineering department of Autoliv UK developed this rollover test method.

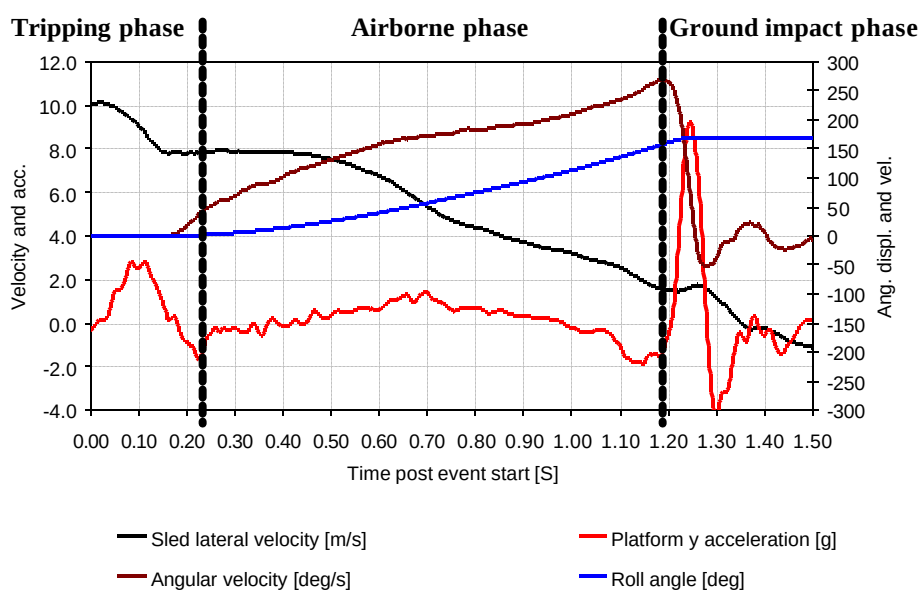

Figure 6
The sled lateral velocity, the platform y acceleration, the roll angle and the angular velocity versus time.

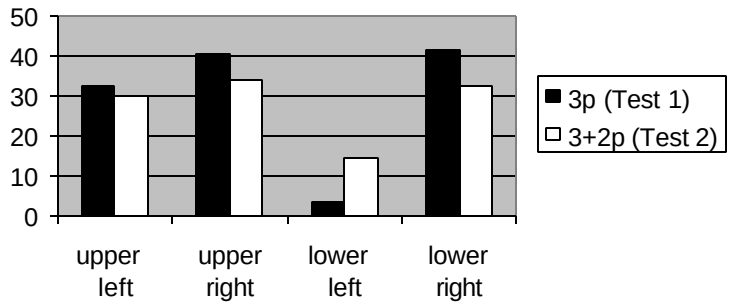

Figure 7
The upper and lower left/right x-chest deflections (in mm).

RESULTS

The results of the tests are shown in separate sections for each crash type.

Frontal impact

In the baseline test with a 3-point belt and a driver airbag, Test 1, the dummy experienced a maximum upper and lower chest x-deflection of 40 and 41 mm respectively. See Figure 7 for the x-deflections for all four chest deflection measurement locations. In Test 2, with an extra 2-point belt (the side support was superfluous), the maximum upper and lower chest x-deflections were reduced from 40 to 34 mm and from 41 to 32 mm respectively.

In Test 3, the seat proved to withstand the forces from the extra 2-point belt. The combination of an extra belt and a 2 kN load limitation proved to be successful regarding unwanted seat deformation. The maximum dynamic deformation of the upper part of the seat back was about 150 mm, see Fig 8.

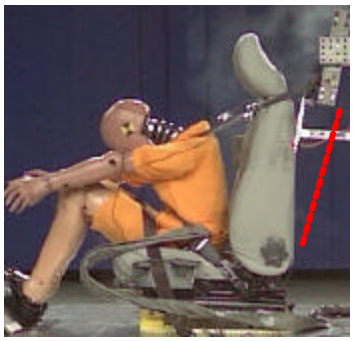

Figure 8
Side view of a frontal impact test (56 km/h) at maximum dynamic deformation of the seat. The dotted red line indicates the initial position of the backrest. The maximum belt force on the upper part of the seat back was 2 kN.

Far side impact

In the baseline tests, Test 4 (3 o'clock) and 8 (2 o'clock), the dummy slipped out of the shoulder part of the 3-point belt. The head-to-sled lateral (sled x-direction) motion was recorded by means of film analysis. The head markers "head up" and "head low", see Figure 4, were used. Figure 9 and 10 show the "head up"-to-sled speed versus the displacement. The speed-displacement histories indicate severe situations for the occupant's head and neck in real life crashes with a far side intrusion in the order of 300 mm. Indeed, the dummy head in the 3 o'clock test impacted with the simulated intruded B-pillar and the consequent HIC36 was recorded to 5875 and the peak upper neck compressive force to 3.7 kN, much higher than the often used reference values of 1000 and 1.1 kN. The maximum head z-angular acceleration and speed were 8700 rad/s^2 and 46 rad/s. These values are also far above the tolerance levels found in the literature, see for example Margulies et al. (1989). See also Figure 11 a) and b) for a view of the event of the head impact in Test 4.

In the 3 o'clock tests, where the side support was used, Tests 6 and 7, the head speed-displacement histories were more or less similar, see Figure 9. The head displacement and speed were limited to 600 mm (from the initial position) and 7 m/s. See also Figure 11 c) to f) with the front views at the same times as in the reference test, Test 4. In the 3 o'clock test, where the 2-point belt but not the side support was used (Test 5), the head lateral speed and displacement were limited compared to the baseline test. However, they were worse compared to the tests with the side support present. Actually, this test (No. 5) indicated a head impact with the (non-present) simulated B-pillar, although the head speed at the time of the virtual collision was much less compared to the baseline test, see Figure 9.

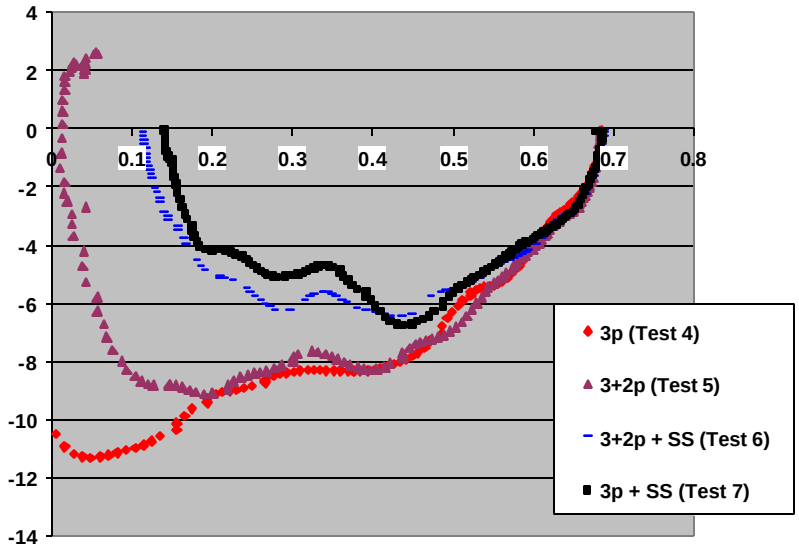

Figure 9
The "head up"-to-sled lateral speed [m/s] versus displacement [m] for the 3 o'clock far side tests. The curves are plotted the first 150 ms or until head-to-pillar contact occurs (Test 4). (Note: 0 m in lateral displacement means 680 mm of head-to-sled displacement and a probable head contact with an intruded (300 mm) far inside of a car compartment.)

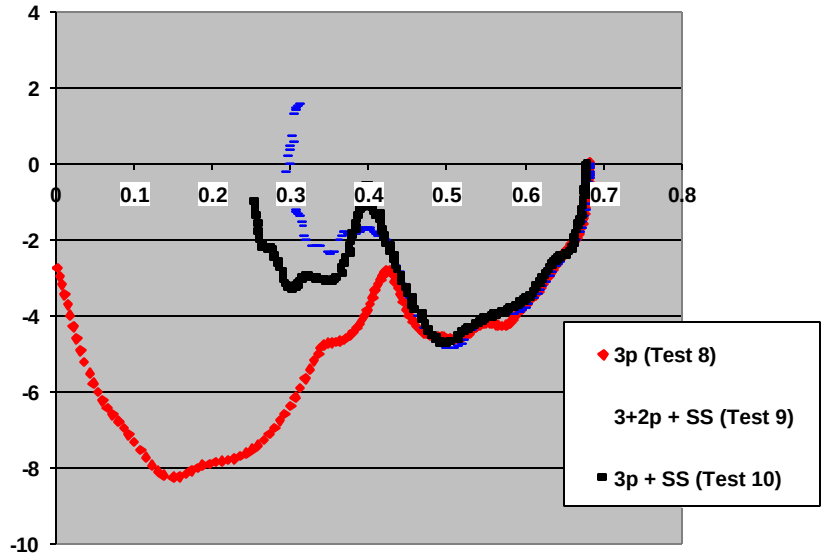

Figure 10.
The "head up"-to-sled lateral speed [m/s] versus displacement [m] for the 2 o'clock far side tests. The curves are plotted the first 175 ms.

a)

b)

c)

d)

e)

f)

Figure 11
The front views of the far side crash simulations for Tests 4, 6 and 7 at 125 ms (a), c) and e)) as well as at 145 ms (b), d) and f)).

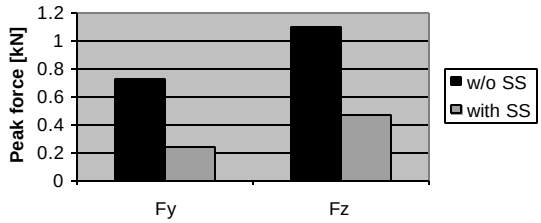

Figure 12.
Lower neck shear and extension forces due to loading by the 2-point belt, with and without the side support (Test 5 and 6), in the 3 o'clock far side tests.

The 2 o'clock tests with the extra restraints, Tests 9 and 10, also showed a remarkable reduction of the head lateral displacement and speed compared to the reference test (Test 8), see Figure 10. Both tests showed similar "head up" speed-displacement histories.

The upper neck loads, Fy and Mx, and the maximum rib deflections and VC were low in all far side tests but the baseline tests, see Table 1 in the appendix. There are currently no proposed limits for a direct belt-to-neck load. Nevertheless, the direct belt loading to the neck caused by the 2-point belt and measured by the lower neck load cell was clearly reduced by the side support in the 3 o'clock tests, from a Fy-peak of 0.73 kN and a Fz-peak of 1.1 kN to 0.24 kN and 0,46 kN respectively, see Figure 12 (Test 5 compared with Test 6).

Rollover

In the baseline test (Test 11) the dummy first slipped out of the shoulder belt moving inboards, then moved outboards and passed the original upright position and leaned to the simulated (car) belt line. When the platform rotation was stopped at 160 degrees, the dummy moved in the z-direction until the slack of the belt was eliminated and the spine was fully elongated. As no roof was present, there was no actual head-to-roof impact to evaluate, see Figure 13. However, with a certain roof geometry, Figure 14 and 15 will give the resulting head-to-inner roof speed. Figure 14 shows the head upward (relative to the platform) versus outboard displacement until the head reaches its maximum upward position (maximum displacement) during the simulated ground impact phase. Figure 15 shows the head upward speed versus the head upward displacement, also until the head reaches its maximum upward position. In Tests 12 and 13 with an extra 2-point belt without and with the side support, the head upward and outboard displacement was significantly limited and at less speed compared to the baseline test, see Figure 14 and 15. For Test 14, with the 3-point belt plus a side support only, the head upward speed versus displacement was more or less similar to the baseline test, see Figure 15. However, due to the inboard restraining by the side support the head kinematics was changed when it came to the ground impact phase. The head travelled against the inner roof in a more inboard position, see Figure 14.

The maximum lower neck axial tension (ground impact phase) and the measured direct belt-to-neck load are shown in Table 2 in the appendix.

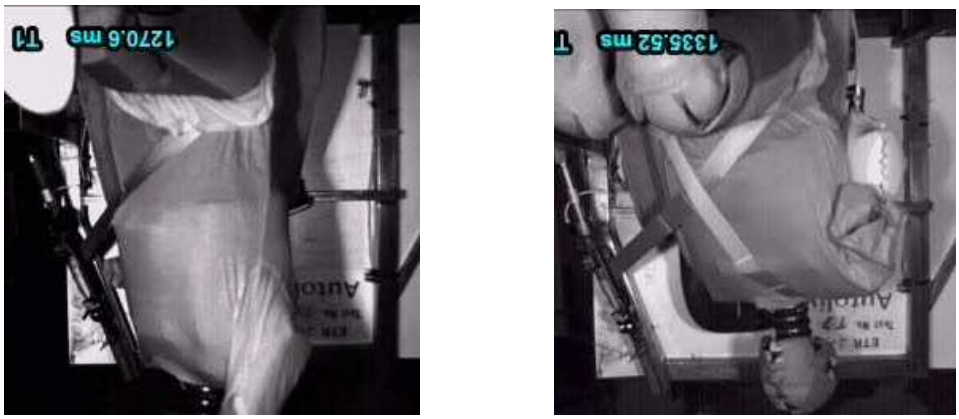

Figure 13.
The front view of the dummy in the rollover tests without and with an extra 2-point belt and a side support (Tests 11 and 13) at the time of maximum head vertical displacement.

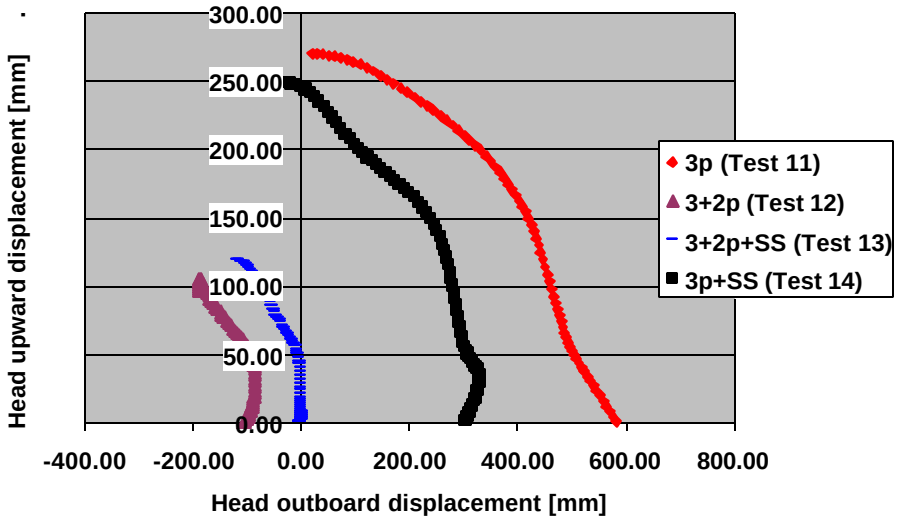

Figure 14.
The head upward versus outboard displacement relative to the platform until the head reaches its maximum upward position (maximum displacement) during the simulated ground impact phase. Note that the side window plane is passed at typically 200 mm of head outboard displacement. The origo corresponds to the pre-crash position.

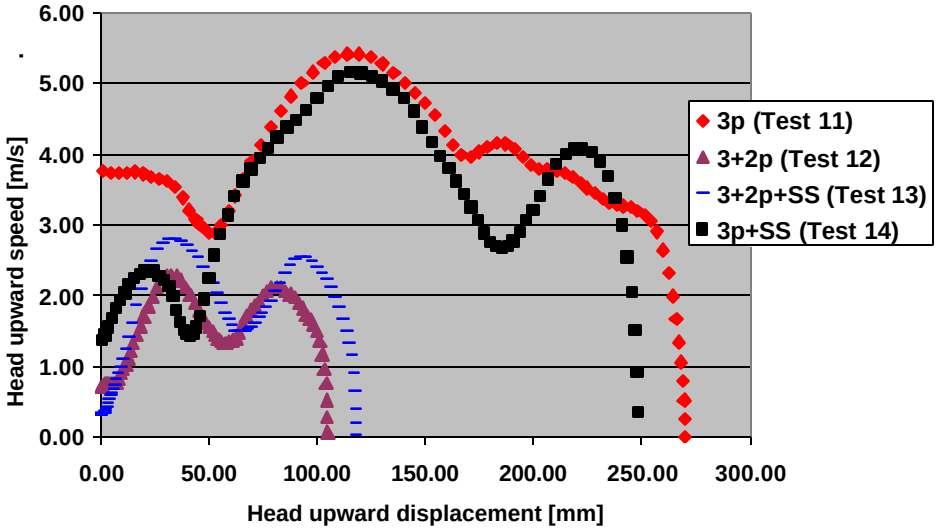

Figure 15.
The head-to-platform upward speed versus upward displacement until the head reaches its maximum upward position.

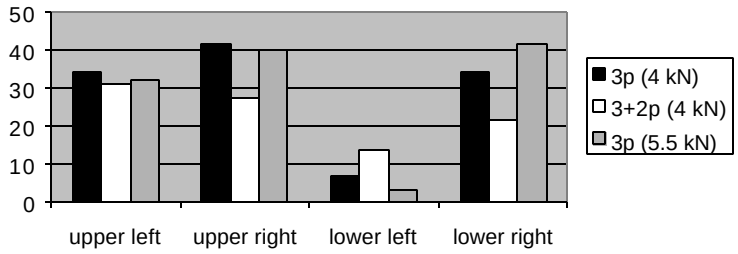

Figure 16.
The upper and lower left/right x-chest deflections (in mm) for Tests 1 and 2 repeated with a 3-point belt 4 kN load level (compared with Test 1).

DISCUSSION

Frontal impact

In the frontal impact tests, the 3+2-point belt system distributed the belt load over the chest better than the 3-point belt alone. The maximum chest deflection was reduced. Of the three injury predictors, maximum chest deflection, acceleration and CTI, the deflection was shown to be the best injury predictor according to a study by Kent et al. (2001). According to the risk curves found in the same study a reduction of the chest deflection from 40 mm to 34 mm corresponds to an AIS3+ risk reduction of about 30%. Elderly people would experience an even greater reduction of injury risk (Kent 2002). The frontal impact Tests 1 and 2 were repeated with a 3-point belt with a load limit of 4 kN, a level found by Foret-Bruno et al (2001) considerably reducing the real life risk of chest injury compared to the 5.5 kN level. The results for a load limit of 4 kN confirmed the conclusions by Foret-Bruno et al. (2001) that the maximum lower chest x-deflection (however not the upper) was reduced by 17 % compared to the 3-point 5.5 kN belt, see Figure 16. The results also confirmed the load distribution feature of the extra belt, which reduced the maximum upper and lower x-deflection with 25 % and 37 % respectively. In previous (not presented here) frontal tests with the HIII similar to Tests 1 and 2, conflicting results were found regarding the chest deformation. In an ongoing research project between Autoliv Research and the Automobile Safety Laboratory of the University of Virginia this controversy is being further evaluated by means of HIII, Thor and PMHS tests.

Far side impact

In the far side tests, the 3+2-point belt plus the inflatable side support system reduced the zone, where there is a potentially high head-to-interior impact speed. This means that the risk for a severe head-to-interior structure impact is effectively reduced. The results indicate that an intrusion of another 100 mm (from 300 to 400 mm) would not result in any head-to-far side interior impact, if the inflatable side support is used together with a standard 3-point belt. The extra 2-point belt seems to be of less importance for this crash type.

According to real life statistics by Frampton et al. (1998) and Augenstein et al. (2000) the risk of a near side occupant being injured in a side crash is worse with a far side occupant sitting adjacent. Therefore, a near side occupant in such a side impact would be less injured due to the improved restraining of the far side occupant.

The second most cause of injury in far side impacts is the belt (Dalmotas 1983, Augenstein et al. 2000). This may be explained by the occupant's iliac crest slipping under the lap part of the belt due to the slack caused by the occupant torso slipping out of the shoulder part of the belt (Figure 11a). However, in the present tests injurious belt loading was neither reflected by films nor by high abdominal rib deflection readings.

Preliminary OOP tests were performed with a HIII 5% female with an instrumented arm blocking the deployment path of the side support bag. The recorded values were below the levels proposed by Duma et al. (2002).

Rollover

In the rollover tests with a far side occupant, the 3+2-point belt system plus the inflatable side support was successful in reducing the zone with a high head speed. This means that the risk for a severe head-to-interior impact is effectively reduced also for this crash type. The rollover tests showed that it is the additional 2-point belt for the far side occupant that is most important for limiting the head's upward and outboard displacement, see Figure 14.

The amount of head z-motion shown in the present rollover tests would probably become at least 70 mm less without the modification set (70 mm being the possible elongation of the modified BioSID spine). This modification of a dummy's spine is essential for a realistic evaluation of potential head-to-inner roof impacts in rollovers.

General

The present study takes into account a limited set of crash types and crash severities. However, they were chosen to be representative for severe frontal impacts, far side collisions and rollovers, where the studied concept was believed to significantly reduce the risk for a car occupant being seriously injured. The amount of intrusion, the crash pulse levels etc. for a particular car model will ultimately determine the actual degree of benefit for the 3+2 point belt system and the inboard side support. Also, for this system to be launched for a car model in a particular market, all legal issues must be solved. This is not taken into consideration in this study.

The influence of the usage of the 3-point belt due to the availability of an extra 2-point belt is not investigated here. The mere existence of two belts could be of benefit, at least the 3-point belt may become more frequently used. The inflatable inboard side support will be of benefit irrespective of the use of the 2-point belt. Another non-explored benefit is the reduction of occupant ramp-up effect in severe rear impacts and the consequently improved effect of the head restraint mitigating neck injuries.

CONCLUSIONS

A series of mechanical sled tests were performed in order to simulate frequent real-life crash scenarios resulting in severe head, neck and chest injuries for an occupant restrained by a standard 3-point belt and a frontal airbag. The dummies used were the HIII, Thor and a new prototype far side and rollover dummy based on the BioSID. The tests were repeated with the inclusion of an extra 2-point belt and an inflatable inboard torso side support. The following benefits were found (rounded values):

- **Frontal:** 20 % reduction of the chest x-deflection (16% upper ribs, 22% lower ribs) was obtained due to the extra 2-point belt. This is of most benefit for elderly people with brittle bones.

- **Far side:** 30% decrease of head horizontal inboard displacement. This reduction should almost eliminate, at least up to 400 mm of side intrusion, the risk of severe head and neck injuries (caused by head contact to the intruded interior) for a far side occupant. Also, a near side occupant would be less severely struck by a far side occupant. The inboard torso side support avoided a possible injurious direct belt load to the neck. The torso side support was found to be of benefit irrespective of the use of the 2-point belt.

- **Rollover:** 60% decrease of the head upward displacement and a 50% reduction of the maximum head upward speed relative to the platform ("car") was obtained with the additional 2-point belt. Depending on the initial head-to-roof clearance as well as to the amount of roof crush, this could mean a considerable reduction of the risk for a far side (and possibly a near side) occupant sustaining severe head and neck injuries in a rollover.

Due to the dramatic effectiveness shown in the mechanical tests an extra 2-point belt supplementing the standard 3-point belt and a small inflatable inboard torso side support should be a cost effective way of further reducing human suffering and societal costs as a consequence of car crashes. An additional inboard side support on its own, provided the 3-point belt is buckled up, would considerably improve the protection of a front seat occupant in a far side collision.

The influence of dummy design on the results in an evaluation such as that presented is critical. It is without doubt important to continue the efforts of establishing suitable far side and rollover dummies with human like kinematics as well as ability to measure loads such as neck and abdominal loads from a seat belt.

ACKNOWLEDGEMENT

The authors acknowledge the ongoing research collaboration with Professor Brian Fildes at Monash University and Dr Laurie Sparke at GM Holden regarding a far-side dummy.

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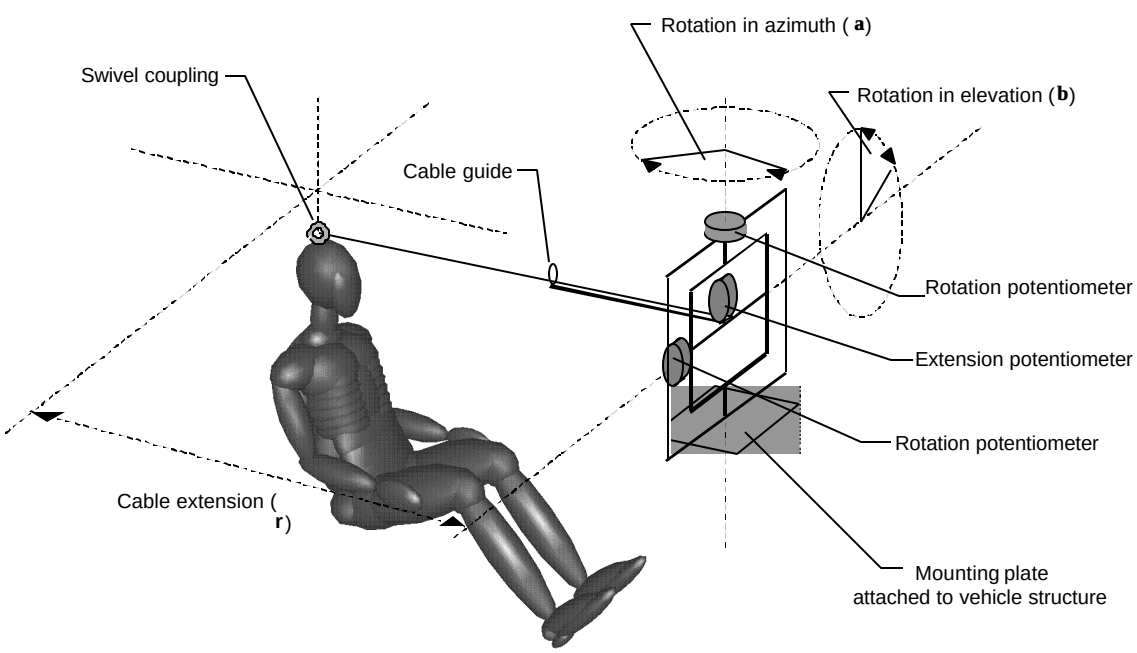
APPENDIX

Table 1
The maximum upper neck loads, Fy and Mx, and the maximum rib deflections and VC in the far side tests

Test	Fy [kN]	Mx [Nm]	Rib d. [mm]	VC [m/s]
4	2.31	96	2.5	0.004
5	-	-	1.8	0.001
6	0.34	30.2	4.3	0.01
7	0.26	20.9	4.9	0.02
8	0.29	32.9	3.5	0.01
9	0.26	21.4	3.7	0.01
10	0.22	15.9	4.0	0.02

Table 2
The lower neck axial tension (ground impact phase) and the measured belt-to-neck load in the rollover tests

Test	Fz [kN]	Belt-to-neck-load [kN]
11	1.2	N.A.
12	0.32	0.28
13	0.38	0.2
14	0.38	N.A.

Figure 1.

Schematic diagram of the Head Relative Position Sensor