# STUDY OF CHEST INJURY RISK PROBABILITY WITHIN THE SENIORS PROJECT FOR 45- AND 65- YEAR OLD CAR OCCUPANTS USING CURRENT AND ADVANCED RESTRAINT SYSTEMS IN SLED TEST WITH THOR DUMMY

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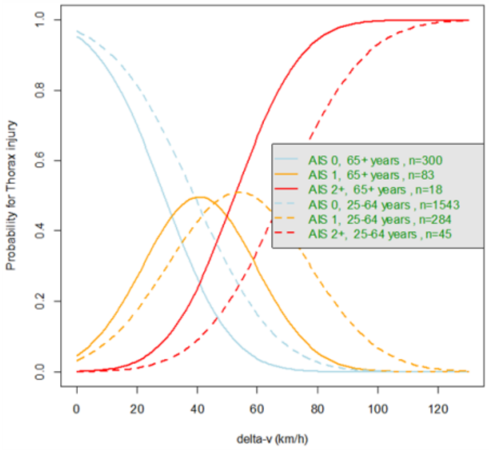
## ABSTRACT

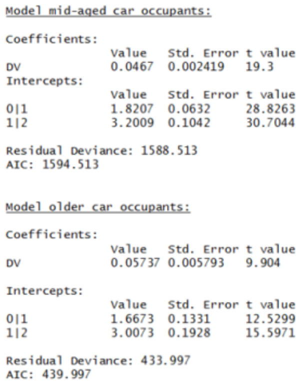
From European accident data the proportion of fatal and severe crashes suffered by over 65 year old road users is increasing. In response to this, the SENIORS project [1] aims to improve the safety of elderly road users by determining appropriate requirements towards passive safety systems. The objective of this paper is to present the results obtained in frontal deceleration sled tests with the THOR (Test Device for Human Occupant Restraint) dummy using different restraint systems to compare the chest deflection for each of them. The frontal sled tests were performed at two speeds 56km/h and 35km/h with the THOR dummy as driver and co-driver following the test procedures defined in the SENIORS project. The different safety systems were used one by one at the low-speed deceleration to understand the effect on the dummy deceleration and chest deflection. The standard restraint systems – frontal airbag and seatbelts – were combined with advanced restraint systems for the driver – Knee airbag (KnAB), Pelvis restraint cushion (PRC) and the Driver Load Limiter Adaptive seatbelt (DLLA) – and for the co-driver position – Pelvis Restraint Cushion (PRC) and the Load Limiter Adaptive seatbelt (LLA). Then, at the higher speed deceleration pulse the basic restraint systems and the chosen combination of advanced safety systems were performed. It is aimed at comparing the chest deflection with the injury risk AIS3+ that is calculated from Rmax and PCA (Injury criteria) for a 45- and 65- year old person. The results observed showed that all the advanced restraint systems reduce the thorax injury risk for both ages 45 and 65 years old, however not always reducing all the IR-TRACC displacement but reducing the Rmax and the PCA calculations. It could also be observed that the most effective restraint system to reduce the thorax high injury for people over 65 years old is Load Limiter Adaptive seatbelt. In this study it can be concluded that with the current standard or advanced restraint systems the chest injury risk for elderly people over 65 years old is very high in high deceleration tests but is also important at lower decelerations. Moreover, the differences in position P1 and P3 are compared in this paper.

## INTRODUCTION

Previous projects on accident research, such as DaCoTa project [2], found that the risk of being killed in a crash was higher for the elderly than for the middle aged person in most EU countries. Based on crash data from 2010 [3] (J. Broughton, 2012), and that older occupants received more often thoracic injuries than younger ones [4] (T. Adolph, 2009). Also, according to [5] (J. Carrol and al., 2009), older occupants (over 52 years of age) were 3.7 times more likely to receive an AIS2+, and 2.8 times more likely to receive an AIS3+ torso injury than younger occupants (12-52 years). Within the SENIORS project a new analysis of the collated European and high-level national crash datasets was carried out (using the in-depth accident datasets from Germany (GIDAS) and the UK (RAIDS)), which confirmed the findings from literature. The data consistently demonstrated a higher risk of serious and fatal injury for older car occupants and the thorax was also identified as the most critical body region for car occupants, which showed the highest share of AIS3+ injuries of all body regions. As explained in [6] and [7], the older occupants of passenger cars – car vehicles manufactured in 2005 or later – have a higher likelihood of suffering from MAIS2+ injuries in frontal car collisions than for middle-aged ones. Moreover, it was seen that the probability of a thorax MAIS2+ injury increases noticeably more by higher delta-v values for older than for mid-aged car occupants.

For example, for a delta-v of 60 km/h the probability of a thorax AIS2+ injury was found as being around 35 percentage points higher for older compared to mid-aged car occupants. According to this conclusion, an injury risk curve for MAIS0+, MAIS1+ and MAIS2+ regarding the delta-v for younger and older car occupants was calculated (Figure 1). Besides this, in SENIORS research it could be observed that the majority of accidents with severe injuries were found in frontal collisions.





```
Model mid-aged car occupants:

Coefficients:
               Value   Std. Error t value
DV             0.0467  0.002419   19.3
Intercepts:
               Value   Std. Error t value
0|1            1.8207  0.0632     28.8263
1|2            3.2009  0.1042     30.7044

Residual Deviance: 1588.513
AIC: 1594.513


Model older car occupants:

Coefficients:
               Value   Std. Error t value
DV             0.05737 0.005793   9.904

Intercepts:
               Value   Std. Error t value
0|1            1.6673  0.1331     12.5299
1|2            3.0073  0.1928     15.5971

Residual Deviance: 433.997
AIC: 439.997
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***Figure 1: Probability of thorax injury severity (MAIS) over delta-v for mid-aged and older car occupants in frontal collisions, GIDAS, cars manufactured in 2005 or later***

Based on the observed facts, the SENIORS project aimed to improve the safety of elderly road users by updating the test procedures and improving the assessments as described in D4.1a SENIORS [8] which determined appropriate requirements towards passive safety systems that better solve senior car users' biomechanical issues. Within the project, specific test characteristics were used to assess elderly safety - such as frontal decelerations at lower levels which were representative with the senior occupant injury.

Also, new multi-point chest injury criteria and risk functions applicable to low deceleration collisions, which considered the age-related characteristics were calculated for the frontal impact THOR 50th male dummy, described in D2.5a SENIORS [9] (Eggers, et al., 2018). Moreover, some advanced safety systems were investigated in the SENIORS project, some of which were presented [10]. To prove the efficacy of the proposed solutions the focus was on thorax injuries. Sled tests were chosen as a widely non-destroyable environment. A total of 14 tests were performed at low deceleration pulse and 4 were performed with a higher deceleration pulse with the THOR dummy in the driver and co-driver position also using different safety systems. Finally, the results were compared and presented regarding young and elderly injury risk.

## TEST DESCRIPTION

### Test environment

The test environment was a compact car BiW (Body in White) which was cut-off behind the b-pillar and mounted in driving direction on the sled platform to simulate a full-frontal crash. In addition, the BiW was reinforced to avoid any unintentional deformation. The occupant compartment was equipped with an instrument panel, steering wheel, and a driver and a passenger seat from the series production. These parts have not been replaced after each test, but were modified to ensure their full integrity to dismiss any damage, except for the seats which were changed anyway 3 and 2 times for driver and passenger position respectively.

*Figure 2: Body in White used for occupant sled tests with the THOR dummy*

### Deceleration test pulse

Two different pulses were used for this sled testing. The first pulse reflects a moderate speed of 35 km/h, whereas the second pulse represents a higher speed of 56 km/h. The low crash pulse was selected because its severity represented well the expectations for moderate speed test which included a reliable basis for comparisons of the performance of the same restraint systems in frontal and oblique impacts. Moreover, literature was reviewed, and it was seen in [11] (Gabler, 2005) a description of the total struck-vehicle delta-v of tow-away far-side impact collisions in the US (NASS-CDS 1993-2002).

Other studies such as the one by Forman [12] used a similar crash pulse for PMHS sled tests in far-side oblique impacts. The high-speed pulse used is representative of mid-sized sedan vehicles and in the range of current test speed. Using a generic pulse at 56km/h, validated with pulses of the NHTSA’s vehicle being representative of European and current vehicles.

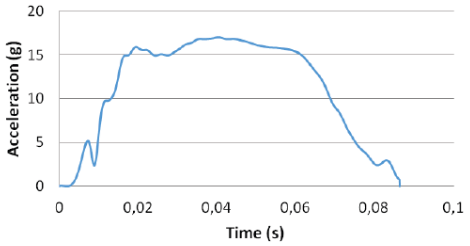


*Figure 3: SENIORS generic moderate speed sled test pulse*

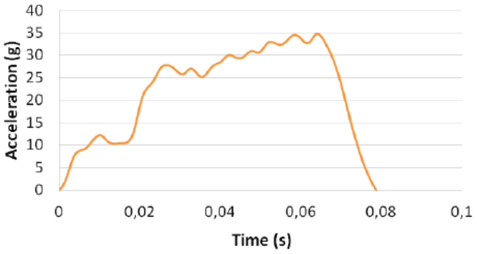


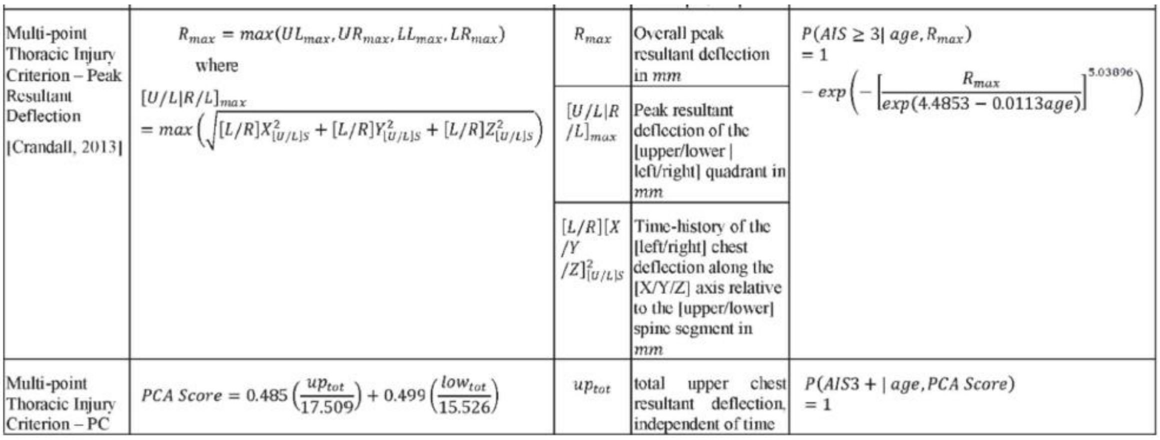
*Figure 4: SENIORS generic high-speed sled test pulse*

### Test tool, ATD

The ATD (anthropomorphic test device) used as test tool was the THOR 50th, which shows superior biofidelity compared to the dummy Hybrid III [13]. For the updated version of this dummy, new thoracic injury risk functions were proposed [14, 15, 16] and the dummy version THOR-M SBL-A is specified by the European New Car Assessment Programme (EuroNCAP) [17] for use in Euro NCAP testing protocols.

### Assessment injury risk curve

The injury probability used for the assessment based on the THOR IR-Tracc chest deflection was the PCA score (Figure 5) and the Rmax values calculated by Crandall [15], which have age variation parameters and show the AIS3+ injury risk for a 45-year-old with respect to a 65-year-old. This makes it possible to evaluate the chest injury risk of old or young car occupants according to the IR-TRACC displacement.



| | | | | |
|---|---|---|---|---|
| Multi-point Thoracic Injury Criterion – Peak Resultant Deflection<br>[Crandall, 2013] | $R_{max} = max(UL_{max}, UR_{max}, LL_{max}, LR_{max})$ where $[U/L\vert R/L]_{max} = max\left(\sqrt{[L/R]X^2_{[U/L]S} + [L/R]Y^2_{[U/L]S} + [L/R]Z^2_{[U/L]S}}\right)$ | $R_{max}$ | Overall peak resultant deflection in $mm$ | $P(AIS \geq 3\vert\, age, R_{max}) = 1 - exp\left(-\left[\frac{R_{max}}{exp(4.4853 - 0.0113age)}\right]^{5.03896}\right)$ |
| | | $[U/L\vert R/L]_{max}$ | Peak resultant deflection of the [upper/lower \| left/right] quadrant in $mm$ | |
| | | $[L/R][X/Y/Z]^2_{[U/L]S}$ | Time-history of the [left/right] chest deflection along the [X/Y/Z] axis relative to the [upper/lower] spine segment in $mm$ | |
| Multi-point Thoracic Injury Criterion – PC | $PCA\ Score = 0.485\left(\frac{up_{tot}}{17.509}\right) + 0.499\left(\frac{low_{tot}}{15.526}\right)$ | $up_{tot}$ | total upper chest resultant deflection, independent of time | $P(AIS3 + \vert\, age, PCA\ Score) = 1$ |

***Figure 5: Thorax injury prediction formula of THOR-M***

**Test restraint systems**

The standard restraint systems – frontal airbag and seatbelts – were combined with advanced restraint systems for the driver – Knee airbag (KnAB), Pelvis restraint cushion (PRC) and the Driver Load Limiter Adaptive seatbelt (DLLA) – and for the co-driver position – Pelvis Restraint Cushion (PRC) and the Load Limiter Adaptive seatbelt (LLA).

The knee airbag module is mounted in the lower instrument panel. The airbag is initially folded in a container and inflated during the crash using a pyrotechnical inflator (Figure 6). The knee airbag usually has a thickness of 150 mm and covers the potential impact area of the knees with the instrument panel. In a crash, the working pressure is approx. 80kPa. With the knee airbag, increased restraining of the pelvis is obtained by means of the upper legs which have the potential to improve the chest-to-steering wheel clearance and reduce the loading to the chest. The pelvis restraint cushion (PRC) is made of an air tight textile material and is installed on the seat pan and below the seat cushion foam (Figure ). The PRC is initially folded and inflated in a crash using a pyrotechnical inflator to a thickness of approx. 100mm. The working pressure of the PRC is approx. 30-40 kPa and its response controlled using a venting hole in the cushion. With the PRC, increased restraining of the pelvis is achieved by means of improved coupling to the seat. With improved coupling, the PRC has the potential to reduce pelvis excursion, pelvis accelerations and chest loading. The PRC has also proven to be effective in the prevention of submarining.

The shoulder belt retractors for all belt systems are equipped with two-level load limiting. In the project, the level of the load limiting was adapted to the impact severity using a pre-defined switch time. The switch time was used to activate the use of the upper or lower or even a combination of both load limiting levels (Figure 7***: Pelvis restraint cushion in a front seat.***). In a vehicle installation, the frontal crash sensors are used to decide the load limiting setting. The load limiting level can also be adapted to other sensor information, such as occupant weight, size, position etc.

***Figure 6: Inflated knee airbag in a frontal sled test.***

***Figure 7: Pelvis restraint cushion in a front seat.***

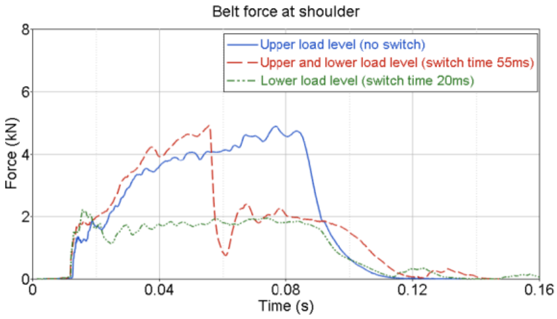


***Figure 8: Belt force at the shoulder for three different setting of the adaptive load limiting***

**Test plan**

At moderate speed pulses the advanced restraint systems were introduced one by one to see the effect on the dummy resultant signals, also two different restraint system combinations (Mix) were selected. At higher speed pulses, only two tests were conducted with the standard restraint system and the best performing restraint system combination from the moderate speed tests. The sled tests were organized as shown in Table 1.

***Table 1: Test lists***

| Position | Pulse | nº | Description | Frontal airbag | Seatbelt | Pelvis Restraint Cushion | Adaptative Load Limiter | Knee airbag | Collapsible steering column |
|---|---|---|---|---|---|---|---|---|---|
| Driver | 35 km/h | 1 | Safety system std for SENIORS | V | V | | | | |
| | | 2 | Safety system std for SENIORS + PRC | V | V | V | | | |
| | | 3 | Safety system std for SENIORS + LLA (t12ms) | V | V | | V (12ms) | | |
| | | 4 | Safety system std for SENIORS + LLA (t27ms) | V | V | | V (27ms) | | |
| | | 5 | Safety system std for SENIORS + KAB | V | V | | | V | |
| | | 6 | Safety system std. for SENIORS + collapsible steering column | V | V | | | | V |
| | | 7 | Mix 1 (DLLA 12ms + KAB 12ms) | V | V | | V (12ms) | V | |
| | | 8 | Mix 2 (DLLA 12ms + PRC 12ms) | V | V | V | V (12ms) | | |
| | 56km/h | 9 | Actual safety restraints system | V | V | | | | |
| | | 10 | Mix (DLLA 12ms + KAB 12ms) | V | V | | V (12ms) | V | |
| Co-driver | 35 km/h | 12 | Actual safety restraint system | V | V | | | | |
| | | 13 | Actual safety restraint system + PRC | V | V | V | | | |
| | | 14 | Actual safety restraint system + LLA | V | V | | V (12ms) | | |
| | | 15 | Actual safety restraint system + LLA different time to fire | V | V | | V (27ms) | | |
| | | 16 | Actual safety restraint system + MIX 1 (LLA t12ms+PRC) | V | V | V | V (12ms) | | |
| | | 17 | Actual safety restraint system + MIX 2 (LLA t27ms+PRC) | V | V | V | V (27ms) | | |
| | 56 km/h | 18 | Actual safety restraint system (no double pretension) | V | V | | | | |
| | | 19 | Actual safety restraint system + LLA t 27ms | V | V | | V (27ms) | | |

## RESULTS

The plots in Figure 7 and Figure 8 show the resultant deceleration from different dummy body parts of the low deceleration tests of the THOR dummy in the driver and co-driver positions. The black curve stands for the reference test at low speed with only the standard restraint systems and the other curves are tests where different advanced restraint systems were added. In consequence, different dummy behaviour for each of the tests could be observed.

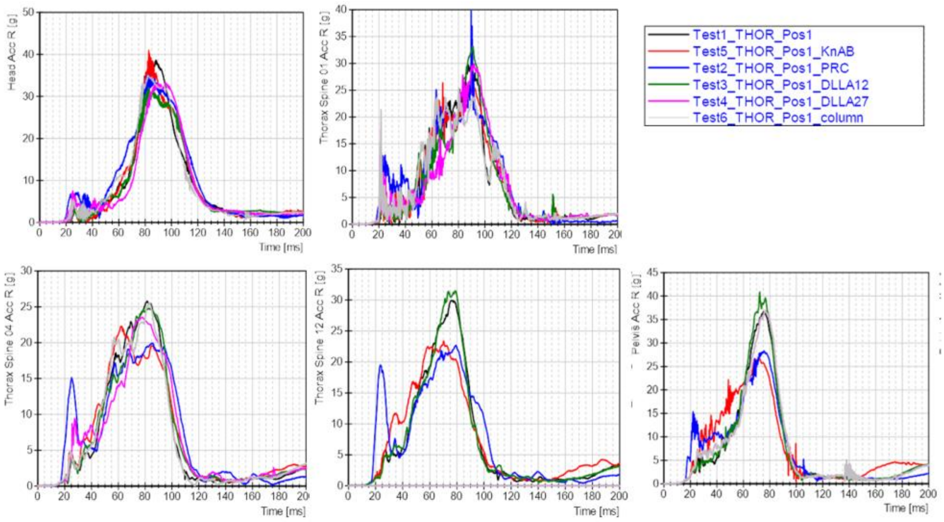


***Figure 7:Deceleration results of different THOR body regions as driver in the sled tests at low speed***

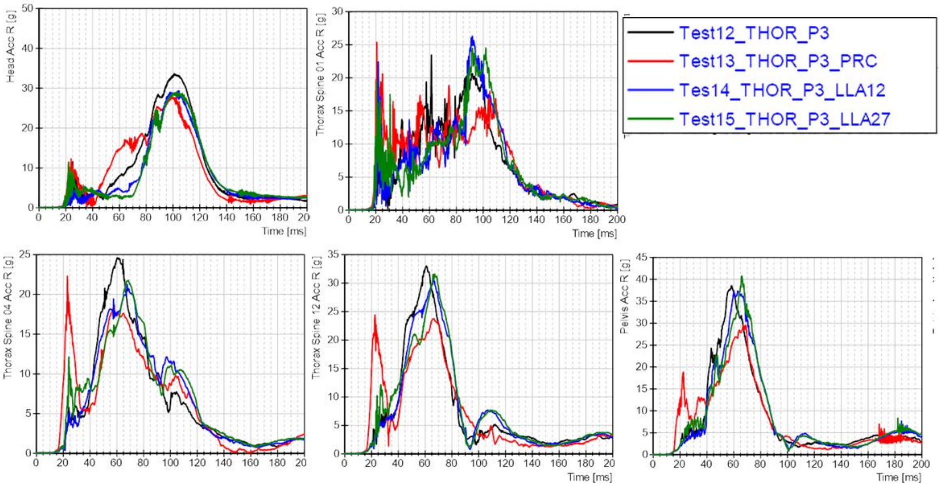


*Figure 8: Deceleration results of different THOR body regions as co-driver in the sled tests at low speed*

Focusing on the chest results, which are the most critical body regions, the chest IR-TRACC displacements were analysed. Table 2 and Figure 1 show a summary of the maximum chest IR-TRACC displacements for each test and the current assessment values Rmax and the PCA for the THOR in the driver position.

**Driver chest test results**

The RIUP (upper right IR-TRACC) displacement was always the highest due to the seatbelt position. This was reduced, by 10-15%, in the third and fourth test where the DLLA – load limiter fired at 12 and 27 ms respectively - was used. This reduction comes together with the slight reduction and increment of the other IR-TRACC displacements. The two red bars in Figure 9 show the results obtained in the Mix 1 and Mix 2 tests with the combination of different restraint systems: Mix 1 with the frontal airbag, the DLLA and KnAB fired at 12 ms; Mix 2 with the frontal airbag, the DLLA and the PRC fired at 12 ms. It can be observed that in both cases the IR-TRACC deflection reductions were nearly similar, with a higher deflection on lower IR-TRACC applied in the Mix 1 test.

*Table 2: Maximum IR-TRACC displacements, Rmax and PCA of the THOR chest in tests 1-10*

| | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 | Test 7 | Test 8 | Test 9 | Test 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| | 35km/h | 35km/h | 35km/h | 35km/h | 35km/h | 35km/h | 35km/h | 35km/h | 56km/h | 56km/h |
| | Standard rest. syst. | str. + PRC | str + DLLA 12 | str + DLLA 27 | str + KnAB | str + collaps. column | Mix 1: Str+DLLA 12+ KnAB | Mix 2: Str+DLLA 12 + PRC | Str. rest. Syst. | Mix: str.+DLA 12 +KnAB |
| Upper Left IR-TRACC (mm) | 33,94 | 24,59 | 26,86 | 23,97 | 22,4 | 22,34 | 23,86 | 23,81 | 33,07 | 57,81 |
| Upper Right IR-TRACC (mm) | 40,88 | 40,13 | 36,75 | 34,55 | 41,51 | 39,38 | 36,81 | 32,89 | 56,4 | 52,78 |
| Lower Left IR-TRACC (mm) | 8,52 | 18,53 | 9,79 | 12,92 | 9,75 | 11,3 | 6,18 | 15,73 | 12,69 | 23,27 |
| Lower Right IR-TRACC (mm) | 33,92 | 39,81 | 29,55 | 34,08 | 26,12 | 32,05 | 20,92 | 32,82 | 42,37 | 29,75 |
| PCA | 5,10 | 5,38 | 4,54 | 4,60 | 4,86 | 4,84 | 4,07 | 4,47 | 7,04 | 6,23 |
| Rmax (mm) | 40,88 | 40,13 | 36,75 | 34,55 | 41,51 | 39,38 | 36,81 | 32,89 | 56,4 | 57,81 |

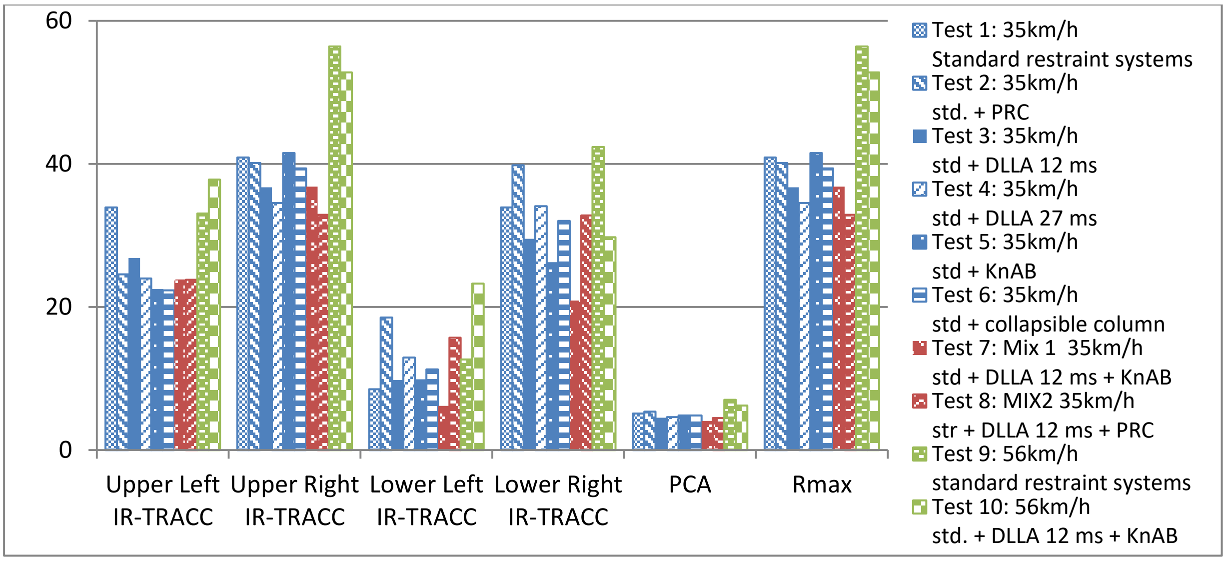


*Figure 9: Maximum chest IR-TRACC displacements, Rmax and PCA values for each THOR dummy in driver position tests*

Comparing the first test with the ninth one both were reference tests where only the standard restraint systems were used – it is clear that at 56km/h the chest deflection is higher mainly for the RIUP chest part. When applying the chosen restraint system combination (Mix 1) to the high speed tests a slight reduction - 6% - of the RIUP IR-TRACC could be observed, but the lower left IR-TRACC showed a highly increased deflection.

According to these observations, the safety system with a higher effect on thorax displacement reduction is the DLLA. It is interesting to evaluate the differences between test 3 and 4 in more depth where the DLLA was activated at 12 and 27ms respectively. Figure 10 shows the forces of the seatbelt at B3 and the belt displacement. The B3 force of the DLLA seatbelt fired at 12ms (green line) which had a lower load limit and a lower seatbelt displacement than the standard seatbelt. However, the B3 force of the DLLA fired at 27 ms (pink line) which had the same lower load limit and a higher belt displacement, but it starts the restraint before all the other seatbelts tested. The lower load limit of the DLLA seatbelts achieved a reduction in the thorax deceleration peak. Also, it maintained the seatbelt force of the DLLA which fired at 27 ms, the seatbelt stay in the correct position on the chest and the chest force was then better distributed between the different IR-TRACCs. Overall, a higher homogeneity of chest IR-TRACC deflections reduced the IR-TRACC peak values and therefore the Rmax value, but did not influence the PCA. Test 6 had the collapsible steering column, however due to the low severity deceleration pulse, it did not collapse. In the videos a small steering wheel displacement was observed in test 6 but also in the other tests. This could be explained by the displacement of the steering wheel position due to the impact. Moreover, there is nearly no difference between test 6 and the reference test 1. The steering wheel used in high-speed tests was also reinforced to become non-collapsible as seen in the previous tests. This fact may be one of the reasons why the chest deflection is so high.

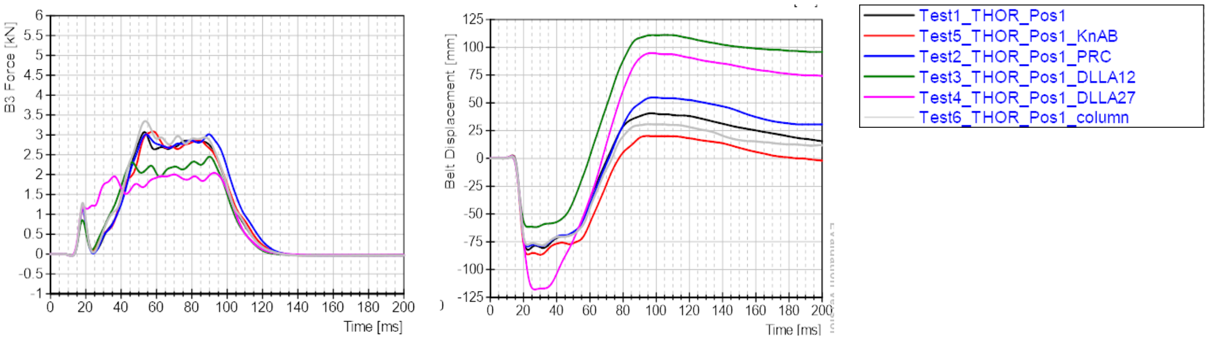


*Figure 10: B3 seatbelt forces and belt displacements*

Besides this, the injury risk was calculated regarding the PCA and the Rmax according to the NHTSA protocol [15] and can be observed in the following Figure 11. At moderate speed it can be seen that the injury risk calculated with the Rmax is lower using the Mix 2 of the available restraint systems – DLLA fired at 12 ms and the KnAB; however, using the PCA it was lower with the Mix 1 of the safety systems - DLLA 12 ms and the

PRC (Pelvis Restraint Cushion). At higher speed tests, the injury risk was in all cases lower using a mix of safety restraint systems – DLLA 12 ms and PRC - and following the same logic as before, this reduction is higher when it is calculated with the PCA value. Nonetheless, it should be said that the injury risk in any case was very high. Also, differences could be observed between injury risks for the 45- and 65-year-old population. This is much higher for elderly car occupants who reached 98% or 95% of injury risk using the Rmax the PCA value and were reduced to 95% and 77% respectively.

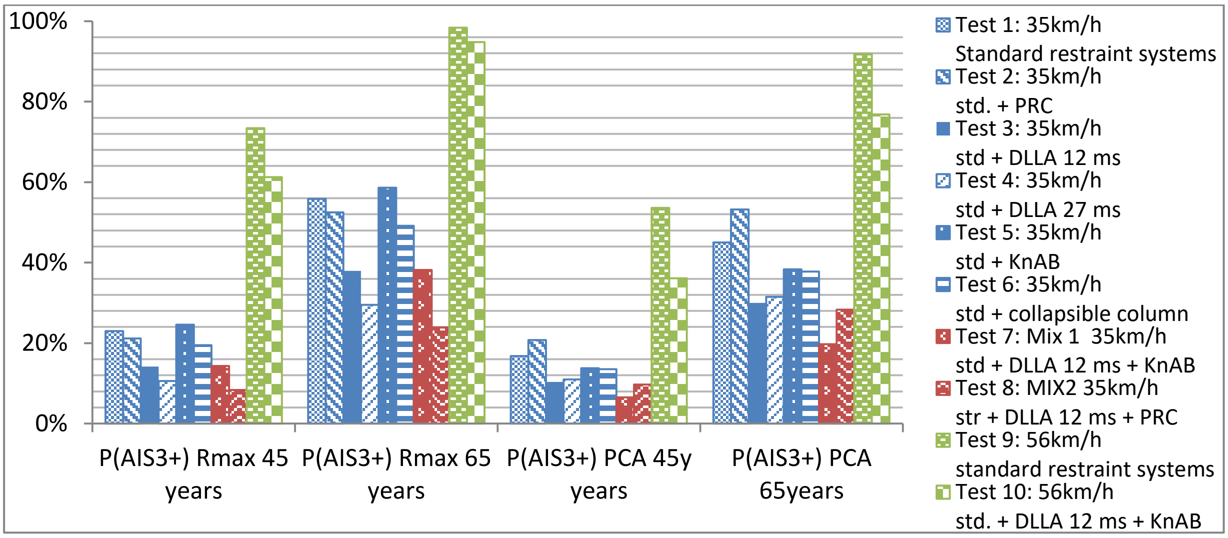


***Figure 11: Injury risks for each test according with PCA and Rmax values for 45 years old occupants and 65 years old occupants***

**Co-driver chest test results**

Regarding the co-driver position, similar analyses were performed. Analysing the chest IR-TRACC displacement, summarized in Table 3 and Figure 13, it can be seen that the most affected IR-TRACCs are the upper left and lower left. The best results observed are in tests 14 and 15 where the DLLA was used, firing the load limiter at 12 and 27 ms. Even though the Left Upper IR-TRACC was not so much reduced, the other IR-TRACC was reduced achieving a lower and more homogenous chest deflection. The PRC achieves an important reduction in LeLO (lower left) IR-TRACC which is interesting due to the higher values observed in the standard test.

***Table 3: Maximum IR-TRACC displacements, Rmax and PCA of the THOR chest in tests 12-19***

| | Test 12: 35km/h | Test 13: 35km/h | Test 14: 35km/h | Test 15: 35km/h | Test 16: 35km/h | Test 17: 35km/h | Test 18: 56km/h | Test 19: 56km/h |
|---|---|---|---|---|---|---|---|---|
| | Standard restraint systems | str. + PRC | str. + LLA 12ms | str. + 27 ms | MIX 1: str. + LLA 12ms + PRC | MIX 2: str. + LLA 27ms + PRC | standard restraint systems | str. + LLA 27ms |
| Upper Left IR-TRACC (mm) | 31,08 | 35,74 | 33,66 | 30,82 | 26,05 | 24,8 | 45,45 | 41,61 |
| Upper Right IR-TRACC (mm) | 24,99 | 18,21 | 16,48 | 17,05 | 18,4 | 15,37 | 25,88 | 19,37 |
| Lower Left IR-TRACC (mm) | 37,06 | 32,44 | 21,61 | 23,42 | 27,55 | | 35,55 | 32,14 |
| Lower Right IR-TRACC (mm) | 12,42 | 11,89 | 10,46 | 11,1 | 11,25 | 11,56 | 13,28 | 16,81 |
| PCA | 5,04 | 4,87 | 4,26 | 4,14 | 4,09 | 3,78 | 6,26 | 5,57 |
| Rmax (mm) | 37,06 | 35,74 | 33,66 | 30,82 | 27,55 | 26,63 | 45,45 | 41,61 |

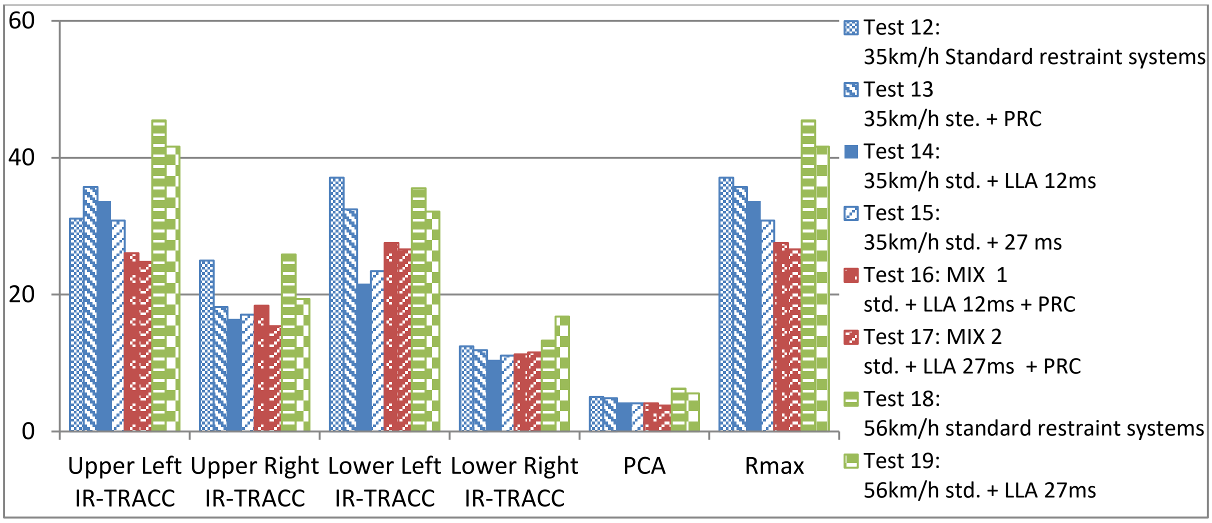


*Figure 12: Maximum chest IR-TRACC displacements, Rmax and PCA values for each THOR dummy in co-driver position tests*

Mix 1 and Mix 2 tests – Test 16 and 17- were a combination of safety systems used to achieve better results than in the other tests. Both tests were performed with the PRC and the DLLA, at 12 and 27 ms. A slightly lower chest deflection was achieved within the Mix 2 test, firing the DLLA at 27 ms, and therefore this combination was used in the second high-speed pulse test. The green columns in the chart are the high-speed pulse tests and as was expected the IR-TRACC displacements are higher. However, the difference between test 12 and test 18 – THOR in P3 position - both with standard restraint systems, is lower than the difference between test 1 and test 9 – with the THOR in the P1 position.

As previously mentioned, it is interesting to analyse the differences between the use of the DLLA firing at 12 or at 27 ms – tests 14 and 15. In the following graphs, the B3 seatbelt force of the DLLA fired at 12 ms – blue line – shows a lower load limiter, which should reduce the thorax deceleration. However, the B3 force of the DLLA fired at 27ms – green line – shows the same lower load limit and a higher belt displacement, but it also starts the restraint before all the other seatbelts tested. The lower limiter of the DLLA seatbelts achieves a reduction in the thorax deceleration peak and maintains the seatbelt force of the DLLA at 27 ms makes the seatbelt stay in the correct position on the chest and the chest force is better distributed between the different IR-TRACC.

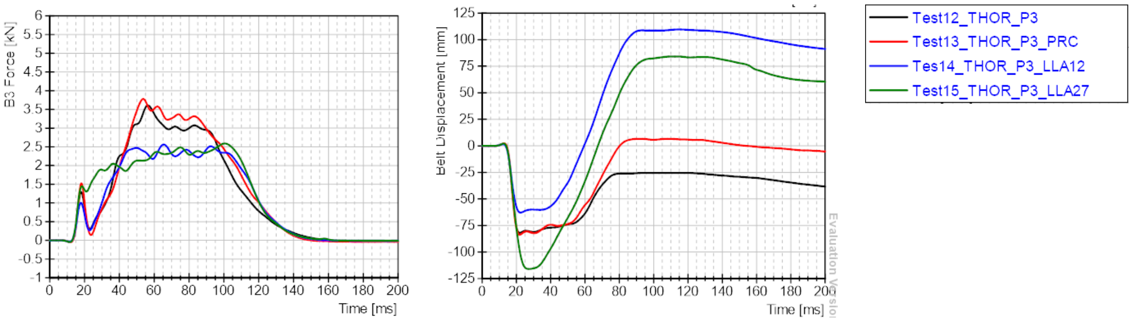


*Figure 13: B3 seatbelt forces and belt displacements in the co-driver position*

Besides this, the injury risk was calculated regarding the PCA and the Rmax according to the NHTSA protocol [15] and can be seen in Figure 14. The injury risk was reduced in all cases with the Mix 2 of safety restraint systems. The injury risk was significantly reduced for 45 year-olds as well as for 65 year-olds achieving 59% of injury AIS 3 or more for elderly people using both the Rmax and the PCA formula. In comparison with the driver results observed – the injury probability is between 61% and 73% the safety systems used for the passenger are significantly better.

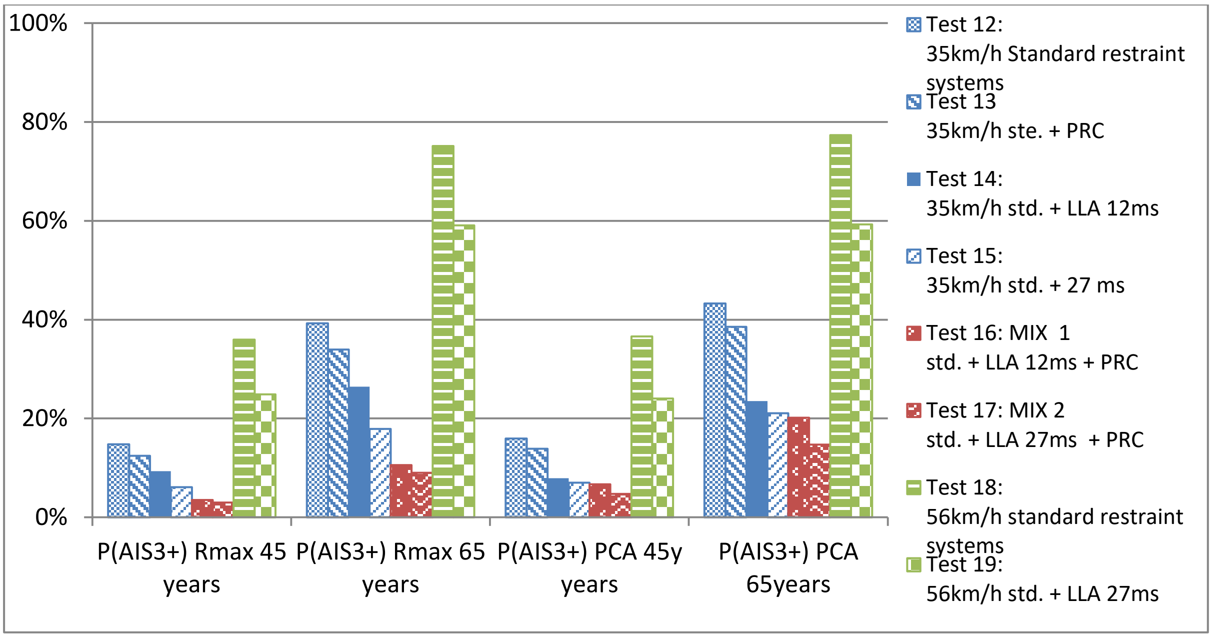


***Figure 14: Injury risk for each test according with PCA and Rmax values for 45 years old occupants and 65 years old occupants***

## LIMITATIONS

The limitations of the current study are the limited number of tests performed. Only one test for each advanced restraint system was performed and therefore it was not possible to adjust or optimize the system's effect. Moreover, the effect of each of the advanced restraint systems could not be studied at a higher deceleration and it could not be studied if they have the same response at both decelerations. Only the chest deflection and chest injury risks were studied, since is the most critical body region for the elderly. However, other body regions should be studied.

## CONCLUSIONS

With the aim of understanding and improving the safety of the elderly as car occupants some sled tests were performed; comparing the thorax injury risks calculated for occupants aged 45 and 65, to see the effect of the different vehicle safety systems at low and high decelerations.

The results obtained throughout this work support the data observed in literature and within the SENIORS project regarding the high risk of severe injuries for senior car occupants in road accidents. It was seen that the injury risk reaches 95% for the 65-year-old driver population. This work also showed that the driver injury risk is always higher than for the passenger, especially in high speed test. These results can be explained by the use of a non-collapsible steering column during the testing.

Furthermore, the testing activities performed also identified the thorax as the main injured body region in these scenarios. The chest deflection results and the corresponding injury risks are relatively high for older car occupants whose chest injury risk is not only increasing in high deceleration tests but also important at lower deceleration ones as well.

Finally, the combination of several standard and advanced restraint systems improved the results of the thorax injury calculations in all cases. Focusing on chest deflection resulting data the best restraint system combination is using the standard restraint systems (regular seatbelts and frontal airbags) with the Load Limiter Adaptive seatbelt for both driver and passenger positions. Although, the results showed that the Pelvis restraint cushion (PRC) was also very effective preventing severe thorax injury.

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