THE EFFECT OF A PRETENSIONER AND A LOAD LIMITER ON A HIII 6y, SEATED ON FOUR DIFFERENT TYPES OF BOOSTER CUSHIONS IN FRONTAL IMPACTS

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ABSTRACT
Over the years, vehicles have become stiffer and front occupant belt pretensioners and load limiters have become standard, showing great benefit in terms of compartment intrusion and injury values. While vehicle safety for children has also increased, there is limited research showing how, with today’s stiffer cars, child safety could be improved by introducing pretensioners and load limiters in the rear seat.

The aim of this study was to evaluate the benefit of pretensioners and load limiters for a HIII 6y seated on three different aftermarket booster cushions (with and without backrest) and on one integrated booster cushion. The results showed that adding a pretensioner and a load limiter to a standard retractor reduced loading of the head, neck and chest for all tested booster cushions. The integrated booster cushion offered the best protection.

REAL LIFE DATA have shown a reduction of abdominal injuries when using booster cushions compared to seat belt use alone (Jakobsson et al. 2005, Arbogast et al. 2004). There are, however, misuse problems with the aftermarket booster cushion where they are either not used at all or incorrectly used (Morris et al. 2000, NHTSA 2004).

Recently Tylko et al. (2005) showed that loading of the chest and neck to the HIII 6y in the rear seat exceeded FMVSS208 IARVs in barrier tests with passenger cars and SUVs. Furthermore, a study by Kuppa et al. (2005) showed that a H3 50 percentile male in the rear seat sustained higher injury values than one in the front seat, indicating that the improvement of rear seat protection is lagging behind front seat protection development. Also, Swanson et al. (2003) have shown that vehicles have become stiffer over the years, which contributes to the need for development of restraint systems in the rear seat.

The aim of this study was to evaluate the benefit of pretensioners and load limiters regarding chest, head and neck injuries to children in frontal impacts. The method used was sled tests where a HIII 6y was seated on aftermarket/integrated booster cushions.

METHOD
The frontal sled tests were performed with a reinforced car body, front seat and rear seat included. Three different 3-point belt retractors were used: a standard configuration, a retractor with pretensioner and a retractor with both pretensioner and load limiter. Hereafter these three systems are referred to as STD, STD+P and STD+P+LL. The belt force limit had a level of 3,3 kN. The retractor was directly mounted on a shelf behind the seat back with direct belt outlet, which eliminated the need for an additional pillar loop.

Four different booster cushions were used, two aftermarket with backrest (BCb1 and BCb2), one aftermarket without backrest (BC) and one integrated (IBC), which is designed into the vehicle seat. All aftermarket booster cushions had belt guidance for the lap belt. BCb1 with belt guidance (pillar loop type) at the shoulder level had a weight of 4.8 kg. The BCb2 had a weight of 2.6 kg. The BC had a weight of 1.2 kg. All booster cushions were tested with the three different seat belt restraints, except for the BCb1, which was not tested with STD+P.

The crash pulse utilized was based on a mean of 5 real life frontal crashes in which AIS2+ injuries were found in belted rear seat occupants. The pulse data was provided from the Folksam Insurance Company, which has installed crash pulse recorders in a range of cars. The $\Delta v$ was 55 km/h, peak acceleration 27g at 25 ms and a mean acceleration of 12.1g. Some additional tests were run with a USNCAP test pulse for a large family car with a $\Delta v$ of 56 km/h, peak acceleration of 38.6g and a mean acceleration of 19.3g.
RESULTS
All results are given in table 1.

## Table 1 Result.

<table>
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<tr>
<th>Seat</th>
<th>Belt</th>
<th>pulse</th>
<th>Shoulder Belt force</th>
<th>Lap belt force</th>
<th>chest defl</th>
<th>chest acc</th>
<th>HIC 15</th>
<th>Nij</th>
<th>Nij t</th>
<th>Nij r</th>
<th>Neck tension</th>
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<td>STD</td>
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<td>STD+P+LL</td>
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<td>69.9</td>
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<td>1.64</td>
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<tr>
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<td>STD+P+LL</td>
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<td>0.64</td>
<td>0.61</td>
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</table>

Real life pulse: In figure 1a and 1b, the effect of pretensioning and load limiting is expressed by the load reduction compared to the configuration with booster cushion with back and standard retractor (BCb1+STD). Adding a pretensioner to the standard retractor reduced the chest acceleration from 16-25%, HIC_15 42-47%, Nij 0-24%, and neck tension 10-17%, and had a limited effect on the chest deflection. When adding a load limiter to the pretensioner, the chest acceleration and neck loadings were further reduced. Additionally, the effect of load limiting reduced the chest deflection by 23% and 27% compared to a standard retractor for the BC and the IBC respectively. The average shoulder belt force was 4.2 kN with the STD and 3.3 kN for the STD+P+LL.

![Figure 1a,b](image-url)
When comparing performance between booster cushions, the primary differences in loadings were found in the chest deflection. The BC and the IBC had lower chest deflection than the BCb1 and the BCb2, when the load limiter was added to the restraint system.

No head impacts or submarining occurred for any belt configuration. In four tests, BCb1+STD, BCb2+STD, BCb2+STD+P+LL, BC+STD+P+LL, the shoulder belt slid off the shoulder during the loading phase, and fastened in the gap between the shoulder and the arm.

**USNCAP pulse:** Some additional tests were run with the more severe USNCAP pulse with the HIII 6-year restrained on the booster cushion BCb1 with the STD and STD+P+LL. In these tests, all the dummy loadings were higher compared to tests using the real life pulse. When the pretensioner and load limiter were added to the system, all dummy loadings were reduced (see Figure 2). The chest acceleration was decreased by 35% but the chest deflection was less affected. The neck loadings were decreased from 11-16%. The shoulder belt force reached 6.4 kN with the STD and 3.7 kN with the STD+P+LL. The shoulder belt slid off the shoulder completely when the dummy was restrained by the standard belt.

**DISCUSSION**

In most cars, the pretensioner and load limiter are standard features for the front seat and have proved beneficial for front seat occupants. The results in these tests showed that the pretensioner and the load limiter in the rear seat were beneficial for the HIII 6y as well. Furthermore, the HIII 6y was best protected using an integrated booster cushion and belt with pretensioner and load limiter (reductions from 21-50% compared to worst condition).

Comparing the two pulses, it is worth noting that the shoulder belt force increased from an average of 4.2 kN to 6.2 kN with the STD belt, which is in the same range of belt force found in the barrier tests presented by Tylko et al (2005). In this study, already at a belt force of 4.2 kN, chest deflection reached a maximum of about 40 mm when restrained with a standard belt, whereby the chest deflection bottomed out due to forward leaning of the upper torso. The shoulder then prevented further deflection of the chest.

Consumer tests such as Euro and USNCAP have had an impact on the crash safety of adult occupants in the front seat. If also safety improvements in the rear seat such as belt pretension, belt force limitation and integrated booster cushion were adequately rated, children in the rear seat would to a greater extent benefit from new technical safety design.

The pretensioner reduced a number of injury values and also reduced the forward displacement of the booster cushion with or without a backrest (see figure 3a and 3b below).

![Figure 2 The reduction of USNCAP pulse loadings with a pretensioner and load limiter relative configuration with STD using a BCb1.](image1)

![a) BC and STD b) BC and STD+P c) IBC and STD+P](image2)

**Figure 3** The pictures show the forward displacement of the dummy and booster cushion about the time of maximum chest deflection (60 ms) (real life pulse).

When comparing the IBC and the BC, the IBC offers a more direct coupling to the seat belt system, without any slack introduced by a loose cushion (see fig 3b and 3c). In addition, the lap belt force with
the IBC was lower than the lap belt force with BCb1, BCb2 and BC. It may have been because the IBC did not have to be restrained by the seat belt, as with the various types of booster cushions.

Figure 4 The pictures show the maximum forward displacement of the dummy restrained with a STD+P+LL in different booster seats (real life pulse).

The displacement of the head was within legal requirements (ECE R44) for all four types of booster seats. However, the IBC resulted in the shortest displacement (see figure 4a,b,c). The webbing pay out did not exceed 150 mm.

The different booster cushions showed similar reductions when adding the different belt functionality, except for chest deflection. The two seats with a backrest showed no reduction of chest deflection when the load limiter was introduced, compared to the two seats without a backrest.

The HIII 6y was sensitive to the belt geometry, where an issue was the belt sliding off the shoulder thereby increasing the risk of impacting the interior. The results of this study indicate the capabilities of the booster cushion to offer the best possible protection when directly integrated with the seat belt system.

**Misuse:** Some additional misuse tests were performed with incorrect belt routing over the guiding horn of the BC. This can only occur when using the booster cushion (with or without backrest) and not with the IBC, since there is no guiding horn included in that design. When the lap belt was above both guiding horns, the dummy slid off the booster cushion, whereby the cushion was not restrained. The dummy submerined, but due to lack of instrumentation, the severity of injury to the abdomen or lumbar spine could not be estimated.

**CONCLUSION**

The study shows reduction of the head, neck and chest loadings to the HIII 6-year seated on booster cushions, with the addition of a pretensioner and load limiter of 3.3 kN to the seat belt.

The variation in performance in different booster seats and the concern of misuse and non-use shows the importance of designing the booster seats together with the seat belt system in order to offer the best possible protection for children.

**ACKNOWLEDGMENT**

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**REFERENCES**


