Retention of rear seat occupants during evasive steering maneuver – effect of seatbelt pre-pretensioner

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Abstract

It has been shown that pre-crash maneuvers may contribute in the injury scenario when the restrained children receive head injuries during frontal impacts, due to partly or complete shoulder belt slip-off. Previous tests with child volunteers showed shoulder belt slip-off during evasive steering maneuver. The aim of the present study was to evaluate the retention effect of seatbelt pre-pretensioner on rear seated crash anthropometric test devices (ATD) during evasive steering maneuver.

A passenger vehicle was equipped with a steering robot, and programmed to drive in 40 km/h and then perform an evasive steering maneuver. Three crash test ATDs were used: the Q6, Q10 and HIII 5th female. The Q6 and Q10 were positioned on an integrated booster while the HIII 5th female was seated directly on the vehicle seat. The seatbelt was equipped with an electrical reversible retractor (pre-pretensioner) with two belt force levels, low and high. In addition, reference tests were run without activation of the pre-pretensioner. Each test configuration was repeated once. The crash test ATDs were monitored using camera, and the video analysis focused on the shoulder belt position and maximum inboard head displacement.

The shoulder belt slipped off the shoulder completely for both Q6 and HIII 5th when restrained by a seatbelt without activation of the pre-pretensioner, while the Q10 had the shoulder belt partly off the shoulder in the same configuration. When activating the pre-pretensioner, already at the lower pre-pretensioner force level the shoulder belt stayed on the shoulder for all three crash test ATDs and the inboard lateral excursion was reduced as compared to no activation of the pre-pretensioner. When the high level was activated, the lateral excursion was further reduced.

The study showed that seatbelt pre-pretensioner can contribute in maintaining the shoulder belt on the shoulder during evasive steering maneuver and therefore, increase the possibility for the shoulder belt to work efficiently if the maneuver is followed by a crash.

Background

The head is the most commonly injured body region among children involved in car crashes irrespective of impact direction (Durbin et al. 2003, Howard et al. 2004, Arbogast et al. 2004). In-depth study of NASS-CDS and CIREN cases has shown that pre-crash maneuvers frequently contributed in the injury scenario when restrained children received head injuries during frontal impacts, due to partly or complete shoulder belt slip-off, resulting in head impacting the seat back in front of the child (Bohman et al 2011a). Previous tests with child volunteers showed shoulder belt slip-off during evasive steering maneuvers (Bohman et al. 2011b), similar results was found when evasive steering maneuvers were conducted with child ATDs (Stockman et al. 2013).

Pre-crash maneuvers prior to crash are common. Stockman (2016a) showed that 40% of all accidents includes a pre-crash maneuver prior to crash. Japanese data, revealed that pre-crash maneuvers such as steering and braking occurred in 60% of all the crashes (Eijma et al. 2012). The rear seat occupants may be more exposed to pre-crash maneuvers compared to front seat occupants, since they are less aware of what is happening on the road and therefore less likely to brace themselves prior the maneuver. Frequently, the rear seat occupant is a child and the shorter stature makes it less likely that the occupant can support themselves with the feet contacting the floor. Also, the rear seat bench has often less pronounced side supports compared to the front seats, and therefore, the rear seat occupant may have less support from the vehicle interior during a swerving maneuver, compared to the front seat occupants.

A seatbelt pre-pretensioner is defined as a retraction of the seatbelt prior to crash, and is usually referred to as an electrical reversible retractor, enabling multiple activations. Pyrotechnical (or mechanical) retensioners, activated based on the crash pulse, have been used in vehicles for decades, and their main purpose is to reduce the slack prior to occupant movement during the crash. The pretensioner triggered by the crash has a high level force but with a short duration, while the pre-pretensioner has a relatively low belt force of 200-600 N and can have a long duration. Although proven very effective in reducing slack and helping to protect the occupants during the crash, the pretensioner has limited possibilities to greatly influence the seatbelt positioning at time of impact. Hence, if the occupant is exposed to an evasive maneuver prior to the crash, only a pre-pretensioner will be able to (given sensing capabilities) act in time to have a chance to interact with the occupant during the pre-crash maneuver. Activating a pre-pretensioner has been shown as a valid countermeasure in order to keep the occupants well restrained during low speed lateral motions (Arbogast et al. 2012, Stockman 2016b) and run-off road events (Jakobsson et al. 2015).

Although studies have been done to understand the possibilities to improve the front seat occupant restraint system, limited efforts have been made regarding the rear seat occupant. There is a need to understand how the restraint system can be improved in order to maintain the rear-seated occupant well restrained during an evasive maneuver potentially preceding a crash. The aim of the study was to evaluate the retention effect of seatbelt pre-pretensioner on rear seated ATDs during evasive steering maneuvers.

Method

Evasive steering maneuvers were conducted on a closed test track. A passenger vehicle was equipped with a drive robot, ensuring repeatable maneuvers. The robot was programmed to drive straight in 40 km/h and then perform an evasive steering maneuver to the left. The maximum lateral acceleration was 0.8g.

In total, three anthropometric test devices (ATDs) were used in the testing; two child ATDs (Q6 and Q10) and one adult ATD (HIII 5th female). The small adult female represents the size a 12 year old child. The Q6 and Q10 were positioned on a two stage integrated booster. The Q6 was positioned on the higher stage and the Q10 was positioned on the lower stage. The HIII 5th female was seated directly on the vehicle seat. Prior each test, the ATDs were centralized in the seat and the lower back and shoulder was in contact with the seat back. There was a snug belt fit, with no additional slack introduced into the belt systems. The ATDs were seated on the left side in the rear seat.

The seatbelt was equipped with an electrical reversible retractor (pre-pretensioner) with two belt force levels, low and high. In addition, reference tests were run without activation of the pre-pretensioner. Each test configuration was repeated once. In total, 18 tests were conducted (see table 1). The pre-pretensioner was trigged when the vehicle passed a photocell, just when the steering maneuver started.

Table 1 Test matrix

	Q6	Q10	HIII5th
Inactive pre-pretensioner	2 tests	2 tests	2 tests
Low level of pre-pretensioner	2 tests	2 tests	2 tests
High level of pre-pretensioner	2 tests	2 tests	2 tests

A GoPro camera (GoPro Hero 3 Black edition) was mounted in the vehicle, providing a front view of the ATDs. The film was captured with 240 frames per second. The video analysis focused on the shoulder belt position on shoulder and lower torso, and the ATD's lateral head excursion compared to the starting position prior the steering maneuver. No data was captured from the ATDs. The acceleration of the vehicle was captured with an accelerometer (Microtron, 7290A-2, 500 Hz), placed in the trunk of the vehicle. A belt webbing load cell (Messring, DK-11-12-21, 2kN, 500 Hz) was attached directly to the upper part of the shoulder belt capturing upper shoulder belt force.

Results

The kinematics of the three ATDs are shown in the figures 1, 2 and 3.

Starting position	Inactive pre-pretensioner	Low level pre-pretensioner	High level pre-pretensioner

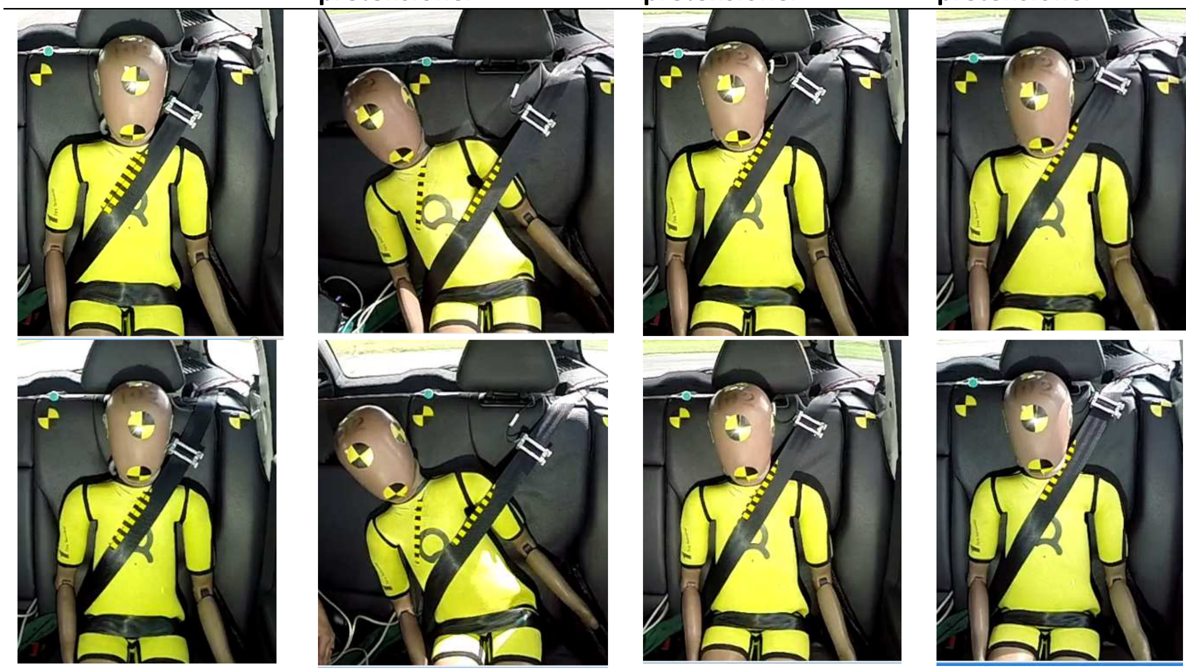

Figure 1 The left column shows the starting positions of the Q6, the next three columns shows the maximum lateral inboard motion restrained without pre-pretensioner activation (second column), pre-pretensioner low level (third column) and pre-pretensioner high level (fourth column). The first row shows the first sequences of tests and the second row shows the repeated tests.

Starting position	Inactive pre-pretensioner	Low level pre-pretensioner	High level pre-pretensioner

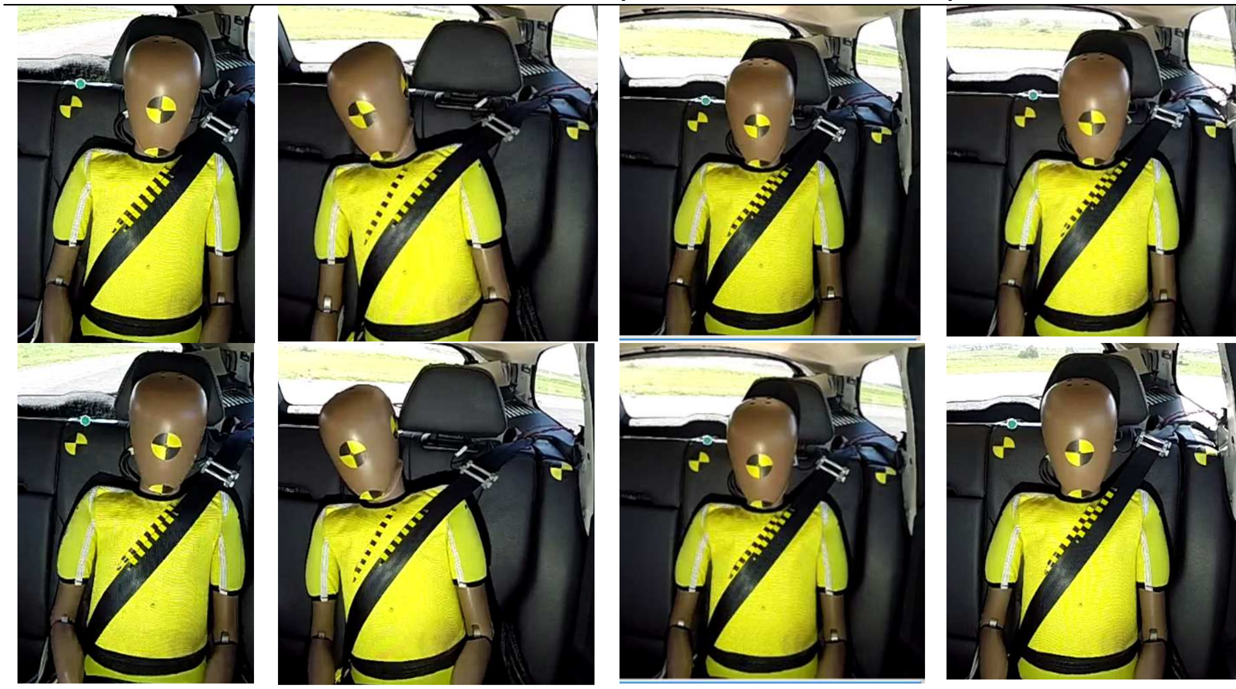

Figure 2 The left column shows the starting positions of the Q10, the next three columns shows the maximum lateral inboard motion restrained without pre-pretensioner activation (second column), pre-pretensioner low level (third column) and pre-pretensioner high level (fourth column). The first row shows the first sequences of tests and the second row shows the repeated tests.

Starting position	Inactive pre-pretensioner	Low level pre-pretensioner	High level pre-pretensioner

Figure 3 The left column shows the starting positions of the HIII5th, the next three columns shows the maximum lateral inboard motion restrained without pre-pretensioner activation (second column), pre-pretensioner low level (third column) and pre-pretensioner high level (fourth column). The first row shows the first sequences of tests and the second row shows the repeated tests.

The initial shoulder belt position was on the mid-shoulder of all three ATDs (see first column in figures 1, 2 and 3). During the maneuver, the shoulder belt slipped off the shoulder completely for both Q6 and HIII 5th when restrained by a seatbelt without activation of the pre-pretensioner, while the Q10 had the shoulder belt partly off the shoulder in the same configuration. The maximum lateral excursions are shown in figure 1, 2, 3 and 4.

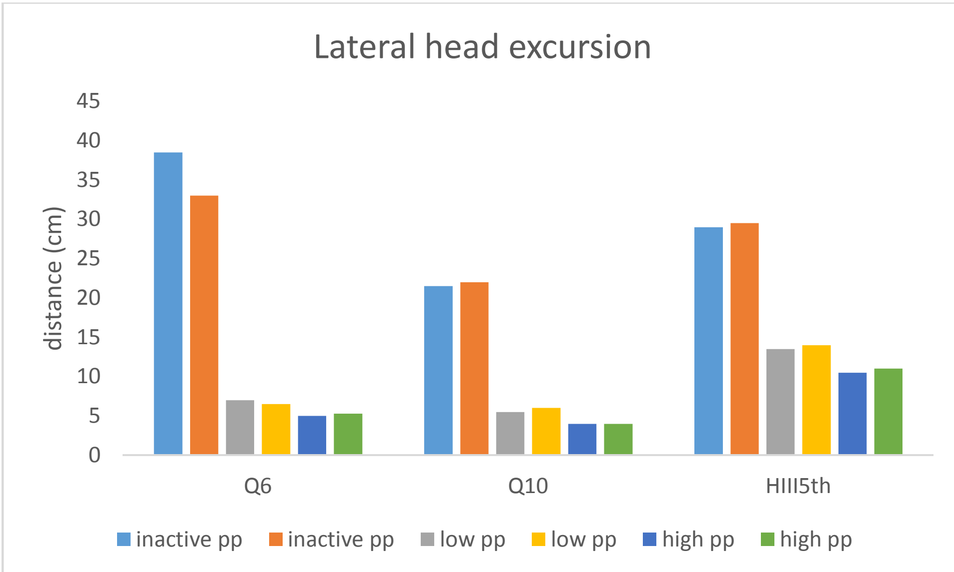

Figure 4 The lateral head excursion of the three ATDs, restrained without activation of pre-pretensioner (no pp), low level of pre-pretensioner force (low pp) and high level of pre-pretensioner force (high pp).

As can be seen in figures 1, 2 and 3, in the tests with activation of the pre-pretensioner, the shoulder belt stayed on the shoulder for all the three ATDs. In addition, the inboard lateral excursion was reduced as compared to the test without activation of the pre-pretensioner. This effect was achieved already at the lower pre-pretensioner force level. When the high level was activated, the lateral excursion was somewhat further reduced (figure 4).

Table 2 Peak shoulder belt force (kN) by activation level of pre-pretensioner and ATD size.

Pre-pretensioner	Q6 (kN)	Q10 (kN)	HIII5th (kN)
Inactive	0,08	0,08	0,04
Inactive	0,08	0,08	0,05
low level	0,25	0,25	0,25
low level	0,26	0,25	0,25
high level	0,40	0,36	0,38
high level	0,43	0,35	0,43

The shoulder belt peak force for the low and high level pre-tensioner tests ranged from 0,25 to 0,26 kN, and from 0,36 to 0,43 kN, respectively. The shoulder belt force was lower in the tests with any pre-pretensioner activation, since the ATDs slipped out of the shoulder belt and did not load the belt to any further extent.

The repeatability of the tests was good. The kinematic responses and shoulder belt movement on shoulder between the first and second tests in each test configuration for the three ATDs were similar (see figures 1, 2 and 3). The difference in lateral head excursion between repeated test was about 0,5 cm, except for Q6 in test without any activated pre-pretensioner were the difference was 5,5 cm (figure 4). The shoulder belt force were similar for each repeated test configuration except the peak shoulder belt force for the HIII5th with the high level pre-pretensioner where the difference was 0.05kN between the two tests (table 2).

Discussion

Previous research has highlighted that evasive maneuvers prior to crash are common. In this study three ATDs of different sizes were exposed to evasive steering maneuvers when restrained with the three-point seatbelt typically available in vehicles today (without pre-pretensioner), and with the same seatbelt with activation of a pre-pretensioner. The ATDs slipped out of the shoulder belt to various extent when the pre-pretensioner was not activated. If this type of steering maneuver had been followed by a frontal impact, the upper torso would not have been properly restrained and resulting in a greater risk of head impact to the vehicle interior.

Of all three ATDs, the Q6 had the largest lateral inboard excursion when the pre-pretensioner was not activated. Due to the Q6's smaller chest depth and shorter sitting height compared with the Q10 and HIII5th, less of the shoulder belt was in contact with the Q6's body and the shoulder belt had less possibility to grab the shoulder. Due to this the Q6 could slide out of the belt. The two larger ATDs, Q10 and HIII5th, also slipped out of the shoulder belt, but with less lateral excursion compared to the Q6. The larger ATDs have wider shoulders providing a larger surface for the shoulder belt to slide on before it slips off the shoulder. Also, the lower part of the shoulder belt was more in contact with the lower torso of the larger ATDs compared to the Q6.

When the pre-pretensioner was activated, already at the low level, with the shoulder belt staying on the shoulder resulting in limited lateral displacement of all three ATDs. If an ATD is restrained and maintained in position by a pre-pretensioner activated during a pre-crash maneuver, it can be assumed that this countermeasure is also beneficial for a human occupant. The results of this study is in-line with the study by Arbogast et al. (2012), who showed that pre-pretensioning reduced the lateral excursion of child volunteers exposed to lateral acceleration. Furthermore, Jakobsson et al. (2015) showed that pre-pretensioner helps maintaining the front seat occupant restrained during run-off road conditions. This study, and also previous studies, show that the early engagement of the torso by the shoulder belt, helps maintaining the upper torso well restrained and prevents lateral movement of the occupant.

All tests were performed with child ATDs restrained on an integrated booster cushion, which does not have any additional seat back side wings as traditional aftermarket booster seats. The high-back booster showed potential for maintaining the shoulder belt on the shoulder during evasive steering maneuvers with child volunteers (Bohman et al. 2011b) and ATDs (Stockman et al. (2013). However, in far-side testing (Tylko et al. 2015) it was found that the side wings was not enough to prevent the child ATD to move excessively outboard towards the nearside occupant space in crash. The same study found that pretensioner reduced the lateral movement, showing the importance of restraining both the child ATD and booster seat as well.

The study was only performed in one vehicle environment. Other vehicle environments is needed to be tested as well, to ensure that the results can be generalized that a pre-pretensioner is a valuable countermeasure for this type of evasive steering maneuver. Furthermore, in order to achieve desired effect of the pre-pretensioner, it is essential that the sensors can detect the upcoming pre-crash scenario in order to trigger the pre-pretensioner in time.

Conclusions

This study showed that seatbelt pre-pretensioner can contribute in maintaining the shoulder belt on the shoulder during evasive steering maneuver for various sizes of rear seated child ATDs. Therefore, it is likely that the pre-pretensioner, given triggered appropriately, will help increase the possibility for the shoulder belt to work efficiently if the maneuver is followed by a crash.

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