A study of the relationship between seatbelt system and occupant injury in rear seat based on EuroNCAP frontal impact

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ABSTRACT

Front-row occupant protection in frontal crashes has benefited from restraint system development and vehicle crashworthiness improvements which have been driven partly by manufacturers' efforts to improve vehicle scores in consumer metric tests. Until recently, occupants in the rear seat have not been considered in most consumer metric tests. As a result, a rear occupant evaluation has been introduced in Europe as a part of the EuroNCAP. Occupant protection performance in the rear seat needs to be evaluated in order to perform well in this newly introduced market requirement. This study investigates the potential benefits of seat belt pretensioners and load limiters in the rear seat for the new EuroNCAP condition. A series of sled tests were conducted following the new EuroNCAP protocol for a 50 km/h full width rigid barrier test. A Hybrid III 5th percentile female (AF5) dummy was seated in the rear seat of a sled buck representative of a small-sized vehicle. A mathematical simulation study of rear seat restraint parameters was first performed to assess chest deflection, head excursion trend and neck injury using different belt load limiters and pretensioning stroke with the Hybrid III 5th percentile female dummy. The results suggest that the belt pretensioner and load-limiter studied here may improve performance to rear seat occupants in the EuroNCAP condition, although more study is needed to evaluate these restraints in other crash scenarios. This study is limited to the Hybrid III 5th percentile female (AF5) dummy in this load case. Restraint performance for larger and smaller occupants also needs to be considered.

INTRODUCTION

For many years, safety engineers have been working on ways to reduce the loss of human lives in high severity vehicle collisions. As a result, various advanced restraint systems were developed to reduce occupants' injury risk. Such endeavors were adopted by safety consumer metric programs such as EuroNCAP. It became very challenging to meet the consumer metric performance criteria without advanced restraint systems. These advanced restraints have focused more on front row occupants.

Recently, EuroNCAP announced the new barrier condition in which a 5th percentile female dummy is placed in the rear seat position in a full width rigid barrier test starting in CY2015. This paper focused on demonstrating performance benefit in this new EuroNCAP barrier test with rear seat 5th percentile female using a combination of a pretensioner and various load limiters (CLL: constant load limiter and PLL: progressive load limiter)[1][2]. Mathematical simulations using LS-Dyna were first conducted to determine the effect of the combination of a pretensioner and load limiter on the dummy's injury values and kinematics in the rear seat. Then, sled tests were conducted using a reinforced sled buck representing a small-size vehicle with a Hybrid III 5th percentile female dummy in the rear seat. The best performing restraint combinations identified in previous mathematical simulations were evaluated.

The load limiters decreased head acceleration and chest deflection of the rear seated dummy in the 50km/h full width barrier crash mode. However, load limiters tended to allow more excursions of the dummy head so that it contacted the front seat back. The pretensioner was applied to balance this increased excursion and as a result, the best performance in this EuroNCAP condition could be obtained through the combination of a retractor pretensioner and load limiter.

Method

A vehicle crash test was done for baseline test followed the European New Car Assessment Program procedure draft version for implementation in January 2015. Mathematical simulations using LS-Dyna were first conducted to determine the effect of the combination of a retractor pretensioner and load limiter on the dummy's injury values and kinematics in the rear seat. Then, sled tests were conducted with a reinforced sled buck of a small-size vehicle.

Vehicle Acceleration

The vehicle pulse selected represents a small-size passenger car in a 50km/h full width barrier impact. The acceleration and velocity-time histories are shown in Figure 1.

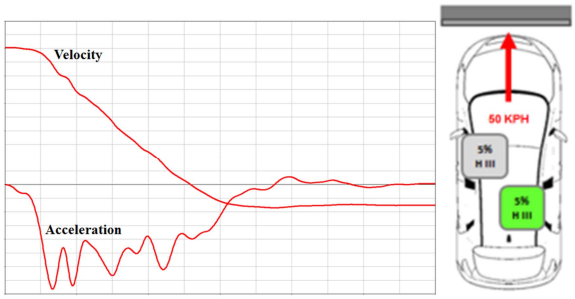


Figure1. Vehicle pulse

Dummy Positioning

A hybrid III 5th percentile female dummy was seated in the right side rear passenger seat. The dummy was seated in the rear right passenger seat by aligning the mid-sagittal plane of the dummy with the front seat centerline. A load cell was placed on the shoulder belt to monitor belt load. The initial positions of the head and H-point, as well as the pelvic angle, torso, femur, and tibia, were adjusted to match the initial occupant position from the baseline crash test.

Injury Criteria

Injury criteria of dummies were examined. In each body region, representative injury was measured and calculated.
The probability of injury was calculated based on the injury criteria of the crash dummy. Basically, injury risk curves were adopted from those used in the USNCAP to calculated scores. [4]
The probabilities of head, neck and chest injuries were calculated by AIS 3+ injury risk curves. Probability of femur injury was calculated by AIS2+ injury. Injury assessment reference value (IARV) was adopted from FMVSS208 to check the compliance. [5]

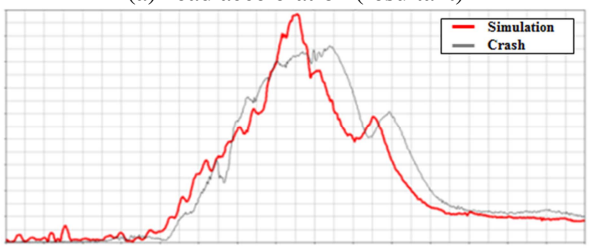
COMPUTATIONAL SIMULATION

Figure2. Pre-test (Crash test vs. Simulation)

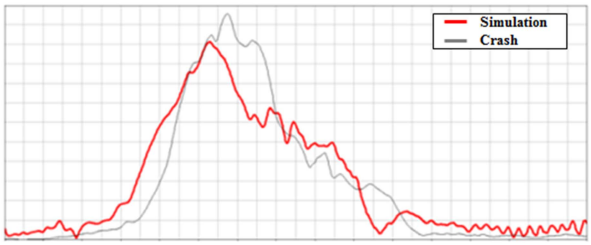
Injury Correlation (Simulation)

A seat belt with an emergency locking retractor (ELR) only (no pretensioner or load limiter) was applied as a restraint to the rear seat Hybrid III 5th percentile female dummy for the base correlated model in both the crash test and simulation. Figure 3 shows the crash test results in gray and the corresponding simulation output in red.

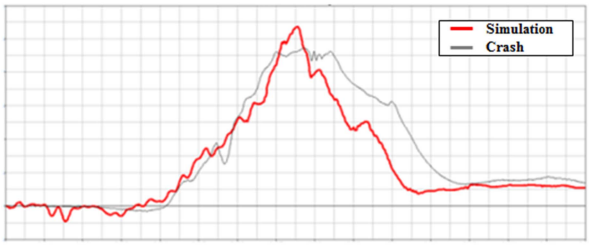
(a)Head acceleration (resultant)



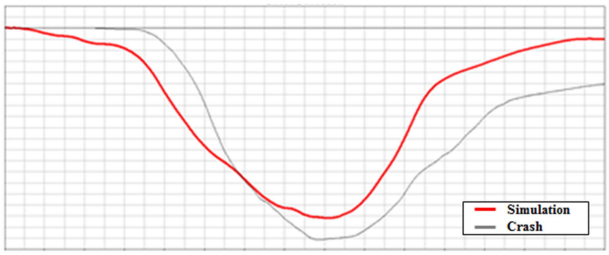
(b) Chest acceleration (resultant)



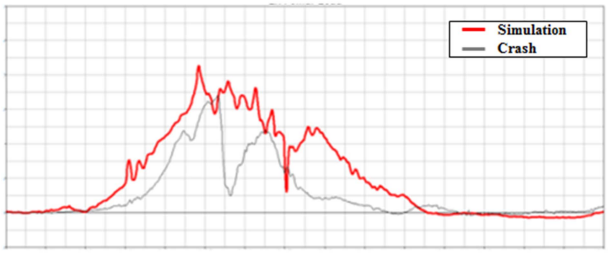
(c) Neck tension and compression



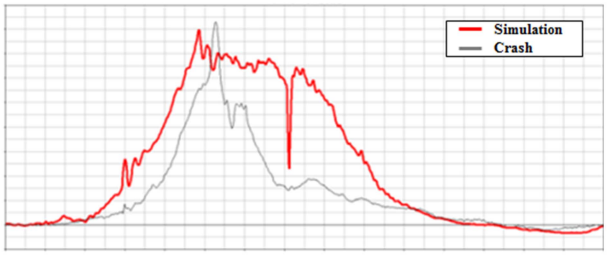
(d) Chest deflection



(e) Femur force (LH)



(f) Femur force (RH)



(g) Shoulder belt force

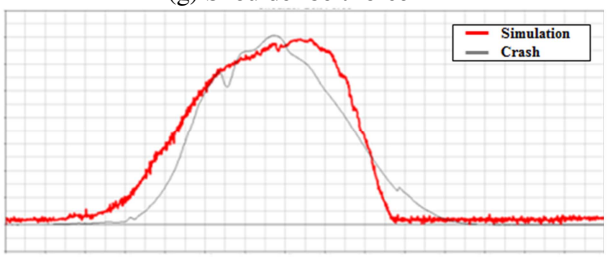


Figure3. Simulation correlation to vehicle test (x axis: time)

Kinematic Correlation (Simulation)

Correlation of the simulation to the test was shown with the head kinematics and lower leg contact to front seat back as shown in Figure 4.

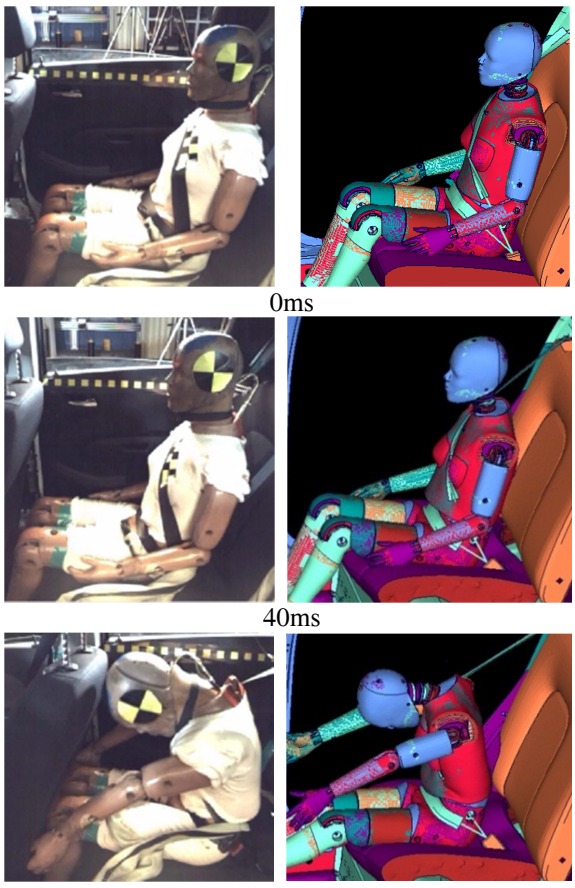


Figure4. Dummy kinematic comparison (left crash and right simulation view)

Parameters of load limiters and pretensioners (Simulation)

In order to observe the effect of the various seatbelt systems on the rear seated female dummy in the EuroNCAP condition, several levels of load limiters were selected. Progressive load limiters were evaluated in addition to constant load limiters (CLL.) Also, two types of pretensioner - standard and high pay-in were added with the ELR and load limiters. Pretensioner deploy time (time to fire: TTF) was also varied. The TTF of a current small vehicle's front row pretensioner was used as nominal time; and 3ms earlier TTF was used to evaluate the influence of deploy time.

Table1.
Study parameters

Load limiter		Retractor Pretensioner	Time to fire
Constant Load Limiter	Low	Standard	Nominal
	Mid		
	High		
	Hyper-high		
Progressive Load Limiter	Low+2kN	High pay-in	Nominal - 3ms
	Mid+1kN		

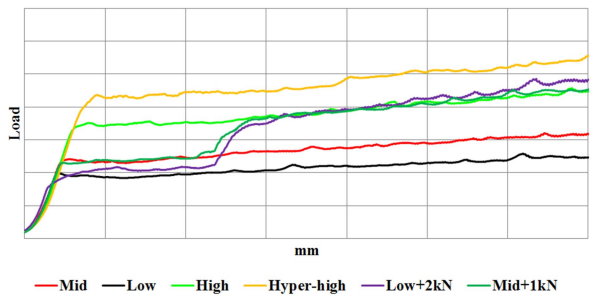


Figure5. Belt load versus displacement

1st study

The first simulation study was done with various load limiters. Hyper high load limiter was not considered in this study.
According to the simulation results shown in Figure 5, the occupant injury values were reduced in the EuroNCAP condition. HIC15, neck tension and chest deflection were improved by 27%, 15% and 51% respectively with the low level CLL compared to the ELR (base) belt system. Chest deflection values tended to decrease as the load limiter levels were lowered. Dummy head excursion and neck injury criteria (N_{ij}), however, increased as load limiter

levels were lowered. All load limiters evaluated in this first study would have resulted in head contact to the front seat back. Figure 7 shows a schematic of the rear seat relative to the front seat, and Figure 8 shows the head excursion for the load limiters evaluated in this first study. The head could contact the front seat back if the dummy's head moves forward more than initial distance A between the dummy's head and the front seat back. Pretensioners were introduced in the second study to investigate whether head excursion could be improved through earlier belt restraint of the dummy.

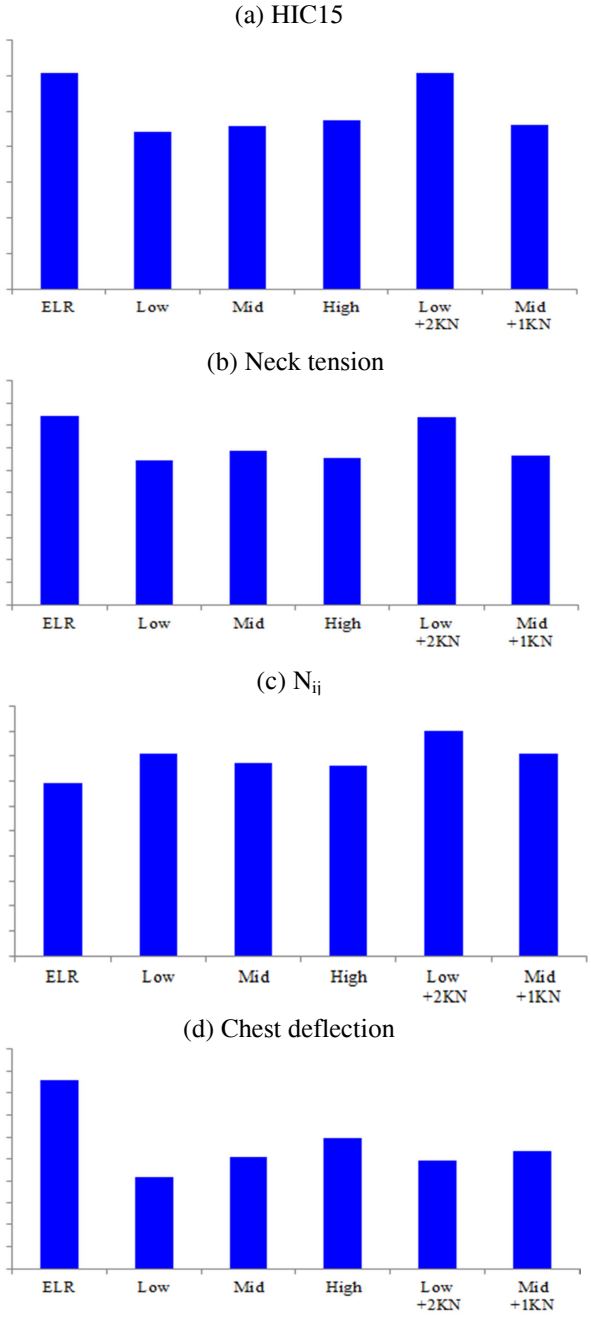


Figure6. Injury values versus load limiter type

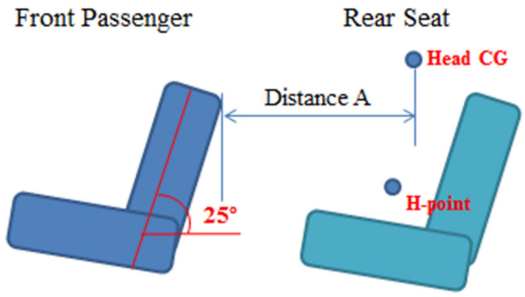


Figure7. Schematic of front and rear seat

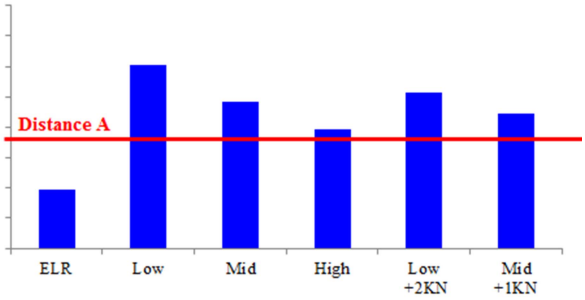


Figure8. Max. head displacement x-axis

2nd study

In the second simulation study, a pretensioner in combination with each level of load limiter was simulated. At the same time, two levels of TTF for the pretensioner were evaluated.

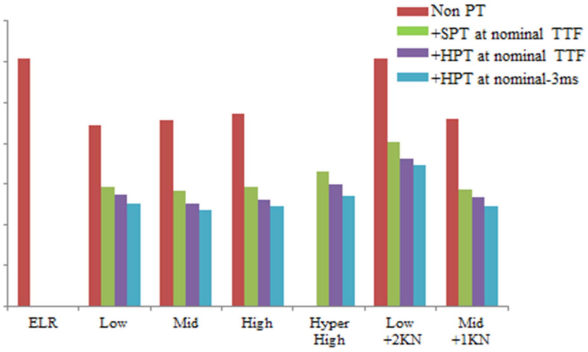
In the simulations with the standard pretensioner (SPT) in combination with a load limiter, the HIC15 value was reduced 33~38% in all cases compared to the HIC15 values produced in the first study without pretensioners. Neck tension and N_{ij} were reduced over 20%. Chest deflection increased over 20%.
In the simulations with the higher length pretensioner, 140% of the SPT retraction length was used. HIC15, neck tension and N_{ij} were decreased over 7%, 4% and 3% respectively compared with SPT. The higher length pretensioner results showed the same pattern as the SPT for chest deflection, which increased over 6% for all load limiter levels.

The pretensioner timing simulations showed decreasing injury values in all regions except chest deflection. HIC15, neck tension force and N_{ij} were decreased over 5%, 3% and 3% respectively for the 3 ms earlier TTF compared with the nominal TTF. Chest deflection increased over 6% in all load limiter levels with the 3 ms earlier TTF.

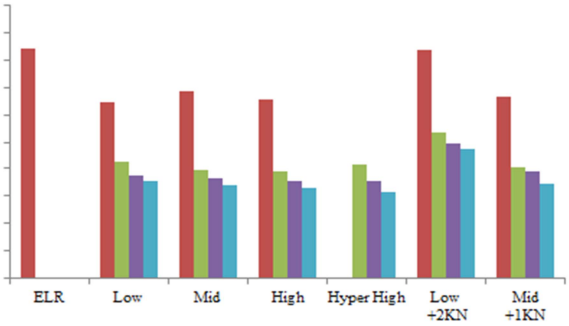
Head excursion relative to the front seat back is shown in Figure 9. All CLL levels without a pretensioner, and the SPT with the low+2 kN progressive load limiter, exceeded distance A. The

mid or higher level of CLL, with any pretensioner evaluated, showed no contact to the seat back.

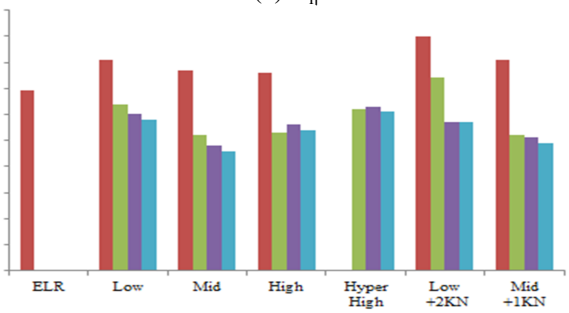
(a) HIC15



(b) Neck tension



(c) N_{ij}



(d) Chest deflection

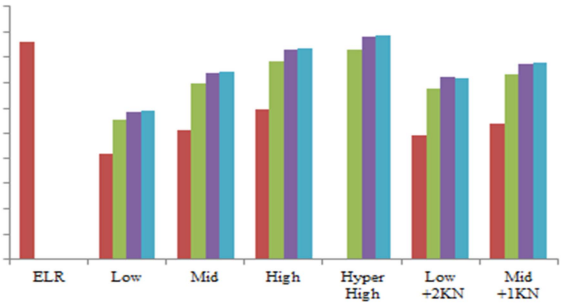


Figure9. Injury values versus load limiter, pretensioner, and TTF

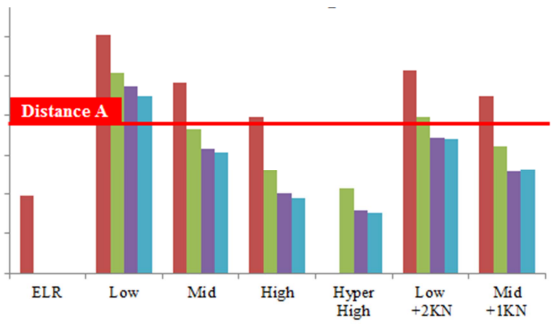


Figure10. Max. head displacement

SLED TEST

To verify the simulation results, the same vehicle acceleration pulse was used in sled tests representing a small-size passenger car undergoing the EuroNCAP 50km/h full width frontal rigid barrier crash test. The front passenger (right side) seat was installed and placed at its mid position of fore-aft travel, with the seat back angle set to 25 degrees, in order to assess potential rear seat dummy head contact. The test set-up (Figure 11) followed the latest EuroNCAP 50km/h full width frontal barrier test protocol. The baseline test was done with the ELR only belt for correlation between the baseline mathematical simulation and physical test.

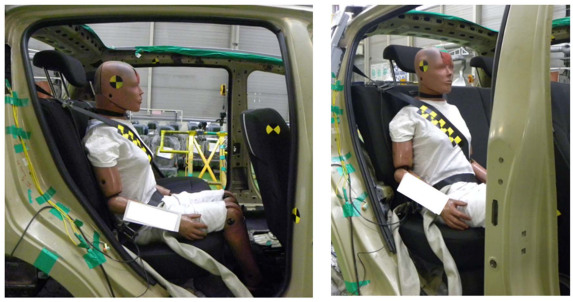


Figure11. Sled test set-up

Sled tests were also conducted using the low and intermediate (mid) level constant load limiters with the ELR and standard powered pretensioner (SPT.) Since the EuroNCAP injury criteria for this condition had not been announced at the time of this writing, the test results relative to the injury risk limits according to FMVSS 208 were used as shown in Figure 12.

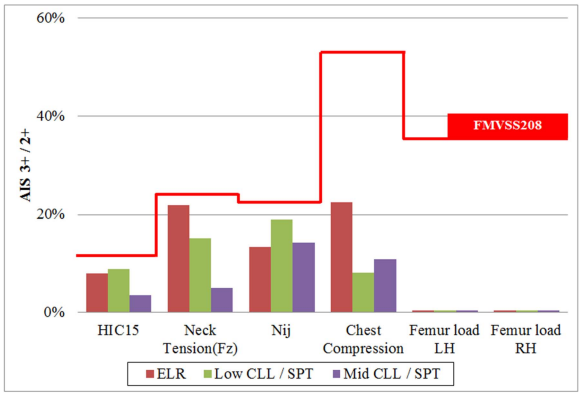


Figure12. Probability of injury

In the test with Low CLL/SPT combination, the chest deflection of AF5 dummy improved by 14% and neck tension improved by 6%, compared to the result of ELR only retractor. However, the dummy's head contacted the front seat back and HIC15 increased by 1% and N_{ij} increased by 5%. The test results of the mid load limiter (Mid CLL/SPT) also showed 11% improvement in chest deflection but 5% higher deflection than that of the low load limiter. The dummy's head did not contact the front seat with the Mid CLL/SPT. HIC15 improved by 4% compared to the ELR only test, and this HIC15 was lower than that of Low CLL/SPT test. Neck tension was also lower by 17% and chest deflection was increased by 11%, compared to the result of the low load limiter and ELR only.

To observe the effect of the increased pay-in amount of the higher length pretensioner on dummy injury in this EuroNCAP condition, sled tests were conducted with the three constant load limiters and the Mid+1 kN progressive load limiter , each in combination with a higher length pretensioner (HPT) [3]. Shoulder belt force is shown in Figure 13 and the dummy test results in Figure 14.

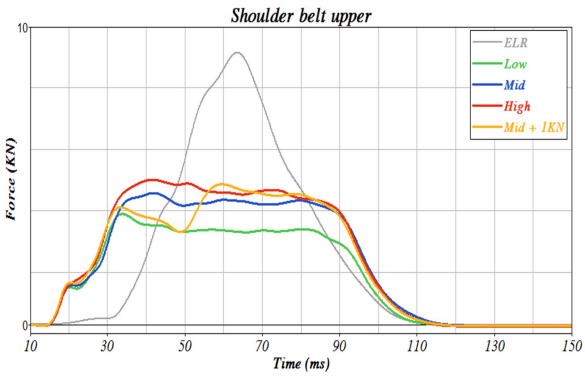


Figure13. Shoulder belt force

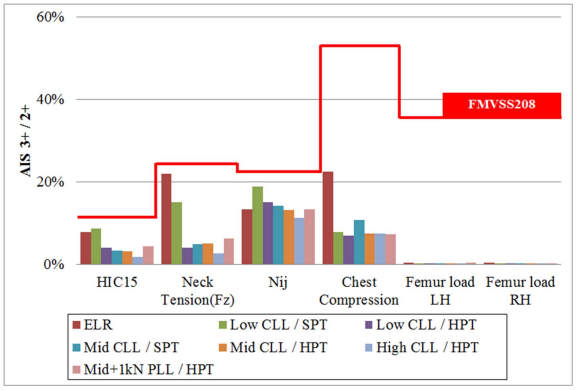


Figure14. Probability of injury

With the CLL/HPT combination, dynamic pay-in amount of belt webbing increased by an average of 50% or greater than that of CLL/SPT.

For the tests with the Low CLL/HPT, HIC15 was decreased by 4%; neck tension decreased by 18%; and chest deflection decreased by 16%. However, the dummy head contacted front seat back. In Mid CLL/HPT, HIC15 decreased by 4%; neck tension decreased by 17%; chest deflection decreased by compared to the SPT, the HPT showed the most decrease in the HIC, neck tension and chest compression by 0.1%, 0.1% and 3% respectively.

Test results showed that CLL High/HPT yielded lower HIC15 by 6% compared to the ELR only and neck tension also reduced by 19%.

The progressive load limiter(Mid+1kN PLL/HPT) showed little effect on dummy injury values compared to the Mid CLL/HPT.

DISCUSSION AND CONCLUSIONS

Simulations and sled tests were carried out for the EuroNCAP 50km/h rigid barrier condition with a belted Hybrid III AF5 in the rear outboard seat position. The conclusions may be summarized as follows:

1. The sled test results for the 50 km/h full width EuroNCAP condition showed that the current belt system (ELR) meets the dummy injury criteria of the FMVSS 208 regulatory requirements for the 5th percentile female dummy which apply in the US in the front outboard seat positions
2. With the load limiter level constant and pretensioner pay-in amount increased, dummy injury trends in the EuroNCAP condition showed a reduction in: HIC15, neck tension and chest deflection
3. As the load limiter level increased, dummy injury trends in the EuroNCAP condition showed a reduction in HIC15 and neck

tension, and an increase in chest deflection

4. Head excursion needs to be considered to determine the combination of pretensioner and load limiter which will prevent hard contact with the front seat back.

The results showed the possibility to improve the dummy injury values in the EuroNCAP full width barrier test when a load limiter and pretensioner are applied in the rear outboard seating positions.

The kinematics and injury values of the dummy in the rear seat could be affected by other factors, such as vehicle acceleration, direction of impact, space between front seat and rear seat and size of occupant, not investigated in this limited scope of study,

Even with the predicted improvement in the EuroNCAP full width barrier condition observed in the simulations and sled tests with the 5th percentile female dummy, protection of larger and smaller size occupants should also be considered.

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