Preliminary Study of the Responses of Hybrid III 5th female, 50th male, Q6 and Hybrid III 5th pregnant female dummy seated in the 2nd row seats of passenger vehicles in sled tests

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ABSTRACT

The objective of this study was a preliminary study of the responses of dummies seated in the 2nd row seat of passenger vehicles in frontal crashes using a sled system. Q6, Hybrid III 5th female, Hybrid III 5th pregnant female, and Hybrid III 50th male ATD were used in the tests. 8-tests were carried out according to a draft protocol for the 2nd row seat evaluation program. The vehicle type was a sedan and SUV’s. The cut-body or jig was used to simulate the ATD in the 2nd row seat/belts of a passenger vehicle. The frontal crash pulse in sled tests was an average acceleration of about 30 vehicle acceleration pulses tested according the KNCAP FFRB test. ATD seating positions were set using the H-point machine. Injury criteria were considered among the HIC15, upper neck tension force, chest deflection. The HIC 15 ranged from 350 to 800 for both a Hybrid III 5th female and a pregnant female. The upper neck tension forces of a 5th female dummy and a 5th pregnant female dummy were also higher than that in FMVSS 208. The kinematics was influenced by the seat and seatbelt characteristics. The sled test results were compared with those of the same vehicle KNCAP FFRB test results. The possibility of fatal injury of Hybrid III 5th female and 50th male ATD in the rear seat could have much higher than in the front seat, especially case of the chest deflection. In addition, the further consideration should be given regarding Y- axis in the regulation at the seat belt anchorage point.

INTRODUCTION

The motor vehicle safety standard refers to a fundamental regulation that should be complied by all vehicles. It should be enacted to prevent traffic accidents and to reduce injuries among vehicle occupants and/or pedestrians at a traffic accident. The Korean government established the “Korea motor vehicle safety standard” in September 1987 under an ordinance of the Ministry of Transportation. For the safety standard regarding the occupant safety of a vehicle at a crash, parts of FMVSS 208 - Occupant Crash Protection, a U.S. motor vehicle safety standard, were introduced in 1993, and the safety standard for occupant safety was established for the FFRB (Full-width Frontal Rigid Barrier) test. Article 102 of the “Korea motor vehicle safety standard” specifies the standard for occupant safety in a head-on collision. The FFRB test is designed the injury criteria of a dummy, by using a Hybrid III 50th male ATD in the driver’s seat and the front passenger seat of a vehicle during the impact speed at 48.3km/h.

Therefore, the KMVSS (Korea Motor Vehicle Safety Standard) to protect a vehicle occupant at the FFRB test is applied to the driver’s seat and front passenger seat only. The KMVSS includes a standard for seat strength and seat belt anchorage strength for the protection of occupants seated on the second or other rows also. In other words, this can be interpreted in such a way that seats after the 2nd row does not have to meet the safety requirement during the FFRB test. We can see that the safety of the driver's seat and front passenger seat has been dramatically improved over the last ten years, largely as a result of the motor vehicle safety standard and the new car assessment system. KNCAP (Korea New Car Assessment System) introduced the FFRB test in 1999 and has used it ever since. The trend of a star rating shows that only three vehicles (18.8%) out of nineteen tested between 1999 and 2001 received
a five-star rating, whereas thirty-seven (97.4%) out of thirty-eight vehicles tested between 2011 and October 2014 received a five-star rating. As shown in Figure 1, a comparison of the 3-year-average AIS (Abbreviated Injury Scale) 4+ injury risk probability for head and chest injuries measured in a 56km/h FFRB test by the KNCAP. It shows that the probability of sustaining a AIS4+ injury risk probability of head injury was reduced from 12.2% to 4.7%, whereas the probability of a joint injury was reduced from 21.6% to 15.1%. This result shows that the probability of a joint injury has been reduced by 70%, compared with the initial stages.

![Figure 1. Average Injury risk possibility (AIS 4+) of ATD in KNCAP FFRB test](image)

When we compared the effects of introducing the FFRB test in KNCAP, based on real accident analysis in Korea, vehicles with a higher star rating were found to be safer. Thus, the MAIS3+ (Maximum Abbreviated Injury Scale) occurrence rate of vehicles with a 4-star rating was found to be 34.2% lower than that of vehicles with from 1 to 3 stars in a frontal crash accident. As described above, the safety of the driver's seat and front passenger seat has been significantly improved owing to the considerable efforts made by car manufacturers, the government, and research institutes. Also, the rate of injury is now quite low. However, little attention has been paid to rear seats, because we can see that a motor vehicle safety standard for the rear seat passengers based on an FFRB test, offset test has not yet been established.

Evans (1987) analyzed that the rear seat lap belt reduces the likelihood of by 18±9 percent, whereas the 3-point seat belt has a 41±4 percent effect for the front passenger seat. Morgan (1999) found that the level of safety increased by 25%, compared with two-point seat belt, as the regulation for the rear seat had changed from the two-point seat belt to the three-point seat belt. Paranteau and Viano (2003) found that torso injuries generally occur due to the seat belt, according to data about frontal crash accidents suggesting that rear seat passengers wear the 3-point seat belt. They also found that abdominal injuries among rear seat occupants caused by the type 1 seat belt also occur when the type 2 seat belt is worn. Suzanne et al (2012) evaluated Hybrid III 5th female ATD and Hybrid III 10 years old on the rear seat. Even when the dummy wore a 3-point seat belt, the dummy in the rear seat was subjected to a more forward movement, compared with the occupant of the front seat. As movements become frequent, the measurement value has an important effect on the head, neck, chest, and lower spine. Sometimes, the head and neck injury value was likely to exceed the reference value. Chest displacement occurs more frequently when the seatbelt is well maintained from the center of the shoulder to the center of the torso.

When we reviewed the results of past studies, analysis was performed on the excellence of the 3-point safety belt, the abdominal injury when the 3-point safety belt is used, and the injury of the 5th female ATD. However, the possibility of injury did not much analyzed by comparing the front and rear seat occupant. The occupation rate of the rear seat in Korea is 21.1%, which is somewhat smaller than the front passenger seat (39.6%). However, we
cannot disregard the vehicle safety of the rear seat due to a low rear seat occupation rate, in order to reduce traffic casualties. Therefore, this study ran a frontal sled test by using a Hybrid III 50th male ATD, Hybrid III 5th female ATD, Hybrid III 5th pregnant female ATD, and a child Q6 on the rear seat, in order to stimulate greater interest in the safety of the rear seat occupant, which generally attracts little attention, and to compare the possibility of injury with the occupant of the front seat, which will require further studies.

**TEST METHOD**

**DUMMY**

The sled comparison test was performed by using a Hybrid III 50th male ATD, Hybrid III 5th female ATD, Hybrid III 5th female ATD pregnant, and child Q6 in the booster seat on the rear seat of a sedan and SUV type vehicles. The Hybrid III 5th female ATD and Q6 were seated in the rear seat for the test, while the Hybrid III 5th female ATD pregnant and Hybrid III 50th male ATD were seated in the same vehicle rear seat for another test (See Figure 2).

![Test set up of Hybrid III 5” & Q6, MAMA & Hybrid III 50” male ATD](image)

The new rear seat and safety belt were installed with each test. The rear seat cushion, seat backs, and safety belt D-ring points were set on the design point. The dummy was seated by checking the H-point machine. In particular, the seating reference point of the Hybrid III 5th female ATD was different from the H-point machine. Hybrid III 5th female ATD was lowered by 6mm below the H-point machine, and the H-point was reset by reducing the seat length rate by the same degree as the forward direction of the car. The Hybrid III 5th pregnant female ATD was seated in the same way as the Hybrid III 5th female ATD. The Hybrid III 50th male ATD was seated with the same seating method as the dummy used for the FFRB test in the motor vehicle safety standard. As there was no steering handle, the upper arm was placed on the seat back and the ring finger was placed on the outer thigh and seat cushion. The Q6 was seated in the booster seat, according to the child safety test method that is being prepared by KNCAP. The frontal sled test speed was 56km/h, and the average acceleration speed pulse was used, regarding the upper and lower limit of the KNCAP FFRB test acceleration speed conducted in 2013 (See Figure 3).
Figure 3. FFRB test acceleration and mean acceleration

TEST EQUIPMENT

The test data was recorded in 10 kHz and filtered according to SAE J211. The scene was recorded from the left and right sides and the upper front, using a 1,000 frame high-speed digital camera. The parts needed for the rear seat test was cut from the actual car (sedan) and made in a jig form. For the SUV car, the second row seat and safety belt part were made in a jig form for the test. The baseline ATD instrumentation included a tri-axial accelerometer at the head CG; a 6-axis load cell at the upper and lower neck; tri-axial accelerometers at the chest and chest potentiometer at chest the Hybrid III 50th male, Hybrid III 5th female, and Hybrid III 5th pregnant female ATD. The same equipment was installed on the Q6 dummy, except that the IR-TRACCs were installed on the lower and upper sternum.

TEST RESULTS

Total 4 vehicles were conducted using the sled system in KATRI (Korea Automobile Testing & Research Institute). The responses of the Hybrid III 50th male, Hybrid III 5th female, and Hybrid III 5th pregnant female ATD seated on the rear seat were compared. The HIC15 of the Hybrid III 50th male ATD were 333, 356, 446 and 498. The HIC15 of the Hybrid III 5th female ATD were 354, 705, 723 and 745. The HIC15 of the Hybrid III 5th female pregnant ATD were 580, 698, 787 and 794. The HIC15 of female ATD had higher than the male ATD, and either came close to or exceeded HIC15 700, which is the injury reference value in FFRB test in the regulation.

The upper neck tension force of the Hybrid III 5th pregnant female ATD were 2.42kN, 2.79 kN, 2.19kN and 1.93kN which is similar to the Hybrid III 5th female ATD (2.62kN, 2.12kN, 2.14kN, 1.52kN). The value for the Hybrid III 50th male ATD were 2.76kN, 2.31kN, 2.27kN and 1.75kN.

The chest displacement of the Hybrid III 5th female ATD were 42.76mm, 42.14mm, 40.3mm and 40.6mm respectively, while those of Hybrid III 50th male ATD were 43.76mm, 49.52mm, 44.8mm and 40.9mm. The chest acceleration 3msec clips of the Hybrid III 5th female ATD were 44.92g, 63g, 63.67g and 52.82g. The chest acceleration 3msec clips of the Hybrid III 5th pregnant female ATD were 41.1g, 51.14g, 58.5g and 61.5g. The female ATD chest acceleration 3msec clip of two vehicles was found to exceed the limits referenced in compliance. The chest acceleration 3msec clip observed for the Hybrid III 50th male ATD were 54.28g, 52.11g, 54.3g and 43.4g. The chest displacement of the Hybrid III 5th female ATD were 47.26mm, 42.14mm, 40.3mm and 40.6mm. The chest displacement of the Hybrid III 50th male ATD were 43.76mm, 49.52mm, 44.8mm and 40.9mm. When comparing the injury criteria between male and female ATD, the male ATD showed a higher value, with the exception of the HIC15. The HIC15 of the child Q5 seated on the booster seat were 502 and 491, and those for upper neck tension force were 2.23kN and 2.17kN, which exceeded the AIS3+20% reference value suggested by the EEVC.
COMPARISON WITH THE RESPONSES OBTAINED FOR THE FRONT SWAR OF SAME VEHICLE FFRB TEST

The results of the FFRB test conducted by the KNKAP were compared with the ATD responses seated on the rear seat, by positioning a Hybrid III 50th male ATD on the driver's seat and a Hybrid III 5th female ATD on the front passenger seat. Figure 4 (left) compares the HIC15 and upper neck tension force, which were both found to be lower than the ATD responses recorded for the rear seat, due to the influence of the load limiter in the airbag and the seat belt. Figure 4 (right) shows the comparison between the head acceleration 3m sec clip and the upper neck tension force. Head acceleration is similar to the front seat, but the upper neck tension force in the rear seat is higher than the front seat.

Figure 4. Peak upper neck tension force and HIC15 (left) / Peak upper neck tension force and peak resultant head acceleration of 3msec(right)

Figure 5 shows the chest deflection of the comparison between shoulder belt load and lap belt load, respectively. The shoulder belt load of the front seat was under 4kN, whereas the lap belt load was distributed between 4.99kN and 11.25kN. The Hybrid III 50th male ATD has a greater lap belt load than the Hybrid III 5th female ATD on the front seat, because the former weighs more. However, the shoulder belt load was similar. It was found that the Hybrid III 50th male ATD received a greater lap belt load and shoulder belt load in the rear seat. When compared with the front seat, the shoulder belt load was applied to the torso more than three times in the rear seat, and chest deflection compared with the front seat was increased.

Figure 5. Peak chest deflection and peak lap belt load (left) / Peak chest deflection and peak shoulder belt load (right)
COMPARISON WITH THE FFRB TEST IN KNCAP

To compare our results with those of the KNCAP, 52 FFRB test results were reviewed among the test results of KNCAP from 2011 to 2014. The Hybrid III 50th male ATD was seated in the driver's seat and the front passenger seat in 2011 and 2012. The Hybrid III 50th male ATD was seated in the driver's seat but the Hybrid III 5th female ATD was seated in the front passenger seat for the evaluations conducted in 2013 and 2014. As a result, the rear seat and front passenger seat were compared for the Hybrid III 5th female ATD, and the test results of the driver's seat, front passenger seat, and rear seat were compared for the Hybrid III 50th male ATD.

The average HIC\textsubscript{15} of the Hybrid III 5th female ATD response of the front passenger seat was 452.72, while the average upper neck tension force was 0.911kN. On the other hand, the average of HIC\textsubscript{15} and upper neck tension force responses recorded for the rear seat were 631.75 and 2.1kN, respectively. The HIC\textsubscript{15} of the Hybrid III 5th female ATD in the rear seat was about 140\% greater than that of the front seat, whereas the upper neck tension force was about 230\% greater. On the contrary, the average HIC\textsubscript{15} among driver, front passenger and rear seat occupant did not show a big difference (i.e. driver's seat: 353.29; front passenger seat: 409.65; rear seat: 427). The average upper neck tension force of ATDs for the driver's seat, front passenger seat and rear seat was 1.42kN, 1.3kN, and 2.27kN, respectively. These results indicate that the female ATD in the rear seat could have sustained more injuries than the male ATD in the front and rear seats (See Figures 6).

The chest deflection of both the driver's seat and the front passenger seat was under 30mm in the Hybrid III 50th male ATD and the Hybrid III 5th female ATD. However, that of the rear seat was 40 - 49mm. The chest deflection of the Hybrid III 5th female ATD was about 270\% more compressed than the front seat average (See Figures 7). Furthermore, it was found that chest deflection in the driver's seat and front passenger seat is not as great as in the rear seat, even though the lap belt load and shoulder belt load increase, regardless of the type of ATD. Figure 8 (right) shows the comparison between shoulder belt load and chest deflection in KNCAP and rear seat frontal sled test. The ATDs of FFRB test in KNCAP is controlled by chest deflection of about 30mm and a shoulder belt load of about 7kN.
Figure 7. Peak chest deflection and lap belt load of 5th female ATD(left) / Peak chest deflection and lap belt load of 50th male ATD(right)

Figure 8. Peak chest deflection and shoulder belt load of 5th female ATD(left) / Peak chest deflection and shoulder belt load of 50th male ATD(right)

KINEMATICS ANALYSIS

Figure 9 shows photos of the ATD prior to the frontal sled test. As the torso position of the seat belt for the Hybrid III 50th male ATD in the rear seat is correct, the seat belt is fastened from the center of the shoulder to the center of the chest. However, the seat belt did not protect the torso of the Hybrid III 5th pregnant female ATD properly in the test, because its sitting height is short and the shoulder belt leans toward the neck due to the presence of the fetus in the abdomen.

Figure 9. 5th female pregnant ATD(left) and 50th male ATD(right) set up in the rear seats
The ATD loaded onto the rear seat moves forward more strongly than that in the front seat. In particular, the test was performed without the front seat. Therefore, restriction of the ATD movement by the front seat could not be tested. It was also found that the seat belt could not control chest displacement at a proper position, due to the presence of the fetus in the lower abdomen of the Hybrid III 5th pregnant female ATD (See Figure 10). The frontal movement displacement of the Hybrid III 50th male ATD was the greatest followed by the 5th female ATD, pregnant female ATD and Q6.

Figure 9. Examples of kinematic responses observed 5th female pregnant ATD and 50th male ATD in the rear seat

DISCUSSION

This study presents the same conclusion as the data of Paranteau and Viano (2003) regarding frontal crash accidents in which rear seat passengers put on the 3-point seat belt, confirming that a torso injury generally occurs due to the safety seatbelt, and that abdominal injuries of the rear seat occupants caused by the 3-point seat belt also occur when the type-3 seat belt is worn. Even though the abdominal load on the dummy was not checked due to the lack of measurement system, the chest deflection of the female ATD in the rear seat was observed to increase by 270% greater than the front seat. Also, the shoulder belt load of the front passenger seat is 5.13kN, whereas rear seat was about 7kN, indicating that the possibility of abdominal injury increases. The test results suggest that we need to devise a method of reducing injuries in actual accidents, by taking into account the fact that the lap belt load on the abdominal area is high.

The percentage of injury risk possibility was analyzed according to the average values of injury criteria of the same vehicle FFRB test conducted by the KNCAP, and the results of the rear seat frontal sled test. For the Hybrid III 50th male ATD on the driver's seat, the injury risk possibility (AIS3+) of HIC15 in the FFRB test was found to be 0.9%; that of chest deflection, 1.1%; and that of upper neck tension force, 0.05%. The joint possibility of an injury being caused by all three factors was 2.04%. Meanwhile, for the Hybrid III 50th male ATD, the injury risk possibility (AIS3+) of HIC15 in the rear seat frontal sled test was 2.6%; that of chest deflection, 18.3%; and that of upper neck tension force, 0.4%. The joint possibility of an injury being caused by all three items was 20.74%. These results indicate that the joint possibility of an injury in a rear seat is greater than in the case of the driver's seat.

For the front passenger seat of the Hybrid III 5th female ATD, the injury risk possibility (AIS3+) of HIC15 in the FFRB test conducted by the KNCAP was found to be 3.5%; that of chest deflection, 1.3%; and that of upper neck tension force, 0.1%. The joint possibility of an injury being caused by all three factors was 4.85%. However, for the Hybrid III 5th female ATD, the injury risk possibility (AIS3+) of HIC15 in the rear seat frontal sled test was 8.7%; that of chest deflection, 30.2%; and that of upper neck tension force, 4.6%. The joint possibility of an injury being caused by all three factors was 39.2%. These results indicate that the joint possibility of injury is also greater than in the case of the front passenger seat. The Hybrid III 5th pregnant female ATD, the injury risk possibility (AIS3+) of
HIC15 in the rear seat frontal sled test was 11.7%, and that of upper neck tension force, 0.4%. As a result, the rear seat is concluded to be less safe than the front seat in the case of both the male and female ATDs.

The shoulder belt part was found to be inappropriate for each dummy, as it was pushed into the lower neck during the test, making it impossible for the chest to absorb the energy properly. As such, it seems that more regulation should be proposed regarding the adjustable Y-axis for short adults, besides the regulation on the X-axis and Z-axis, when defining the shoulder belt of the rear seat belt in the motor vehicle safety standard. It seems that the motor vehicle safety standard and NCAP for rear seat safety and new car safety assessment should be implemented immediately, as the possibility of a head, neck, or chest injury is higher in the rear seat than in the front seat.

SUMMARY AND FUTURE WORKS

It was observed that the performance of safety for the rear seats and restraints was different compared with the front seat in a same vehicle. The possibility of fatal injury of Hybrid III 5th female and 50th male ATD in the rear seat could have greater than in the front seat, especially case of the chest deflection. For the Hybrid III 50th male ATD on the driver's seat in FFRB test, the joint possibility of an injury risk (AIS3+) was 2.04%. But for the 50th male ATD on rear seat, the joint possibility of an injury risk (AIS3+) was 20.74%.

For the Hybrid III 5th female ATD on the front passenger seat in FFRB test, the joint possibility of an injury risk (AIS3+) was 4.85%. However, for the 5th female ATD on rear seat, the joint possibility of an injury risk (AIS3+) was 39.2%. In case of the injury risk possibility (AIS3+) of chest deflection of passenger seat in the FFRB test was 1.3%, but rear seat frontal sled test was 30.2%. As a result, it was found that the rear seat was to be less safe than the front seat in the case of both the male and female ATDs. Also it was found that the possibility of injury risk for the female ATD on rear seat in frontal crash was greater than male ATD. In addition, the further consideration should be given regarding Y-axis in the regulation at the seat belt anchorage point.

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