

EFFECTIVENESS OF SEATBELT FOR REAR SEAT OCCUPANTS IN FRONTAL CRASHES

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ABSTRACT

Recently, the general public in Japan is attaching increasing importance to the wearing of seatbelts by rear seat occupants. Some projects have been launched to have more rear seat occupants wear seatbelts in Japan. The National Agency for Automobile Safety and Victim's Aid (NASVA), for example, conducted a research project to evaluate the effectiveness of wearing a seatbelt based on crash tests. Full-width rigid barrier tests were conducted using Hybrid III AF05 and 3YO dummies in belted or unbelted conditions in the rear seat. This paper summarizes the analyses of crash tests in this project.

For the belted AF05 and 3YO in the rear seat, the injury criteria were relatively low since contact with the car interior was prevented by a seatbelt, though the chest deflection of AF05 was large by the shoulder belt. However, when the AF05 was not belted, the knees and the head made contact with the seatback of the front seat and the head of the front seat dummy, respectively. The injury criteria were extremely high and exceeded the injury assessment reference values (IARVs). Due to this impact by the AF05, the injury criteria of the driver dummy became high. The unbelted Hybrid III 3YO was thrown around inside the passenger compartment, making contact at several locations. It was demonstrated that a seatbelt is useful for preventing hard contact with the vehicle interior. However, some challenges remain, one of which is that the loading by the conventional seatbelt is too large for the Hybrid III AF05 chest.

INTRODUCTION

In general, the percentage of rear seat occupants wearing seatbelts is small compared to that of front seat occupants. For example, according to the

investigation by the Japan Automobile Federation (JAF) in 2005, the percentage of front seat occupants wearing seatbelts was 92.4%, against a mere 8.1% in rear seat occupants in Japan [1]. Because of these low percentages as well as the wide age distribution of occupants in the rear seat, the target population is limited, which makes it rather difficult to conduct a statistical analysis to investigate injuries to the rear seat occupants.

Many accident analyses have demonstrated the effectiveness of wearing a seatbelt for injury risks to occupants in rear seat. Morgan [2] reported that the reduction of fatalities is 32% based on the Fatality Analysis Reporting System (FARS) in the US. In the UK, Cueradan [4] reported 41% for the reduction of MAIS 1+ injuries using the Co-operative Crash Injury Study (CCIS). Shimamura [3] estimated the effect of seatbelt for rear seat occupants by applying logit model to the national accident data in Japan (1995-2000). If the unbelted rear seat occupants changed to belted, the number of fatalities of rear seat occupants would decrease by 45%.

Some features are observed in injury body regions for rear seat occupants. According to the accident analyses by Cuerdan [4], the frequency of chest injuries by shoulder belt is largest in the belted occupants in the rear seat. He also reported the frequencies are high in head and lower extremity injuries due to contact with the front seatback in addition to whiplash injuries. In unbelted rear seat occupants, the frequency of head injuries was largest, and the injury sources were front seats, head restraints and external objects.

Parenteau and Viano [5] also examined the injury risks to occupants over age 13 who were in rear seats and involved in frontal impacts using the US accident data (NASS-CDC 1991-1998, FARS

1988-1996). For occupants with a 3-point seatbelt in the rear seat, the frequency of chest injury was largest. For unbelted occupants, injuries to various body regions such as upper extremities, head and upper extremities occurred frequently. Based on these results, they concluded that a seatbelt force limiter and energy absorption of the front seatback and of the vehicle interior would be effective for the protection of rear seat occupants.

The influences of the behavior of the rear seat occupants on the injury risks in front seat occupants were investigated. Using the national accident data in Japan, Ichikawa et al. [6] showed that the injury risks to front occupants were five times higher when there were occupants in the rear seat. Broughton [7] also examined the increasing injury risks to front seat occupants based on the UK accident data, and found that the injury risks increased by 1.79 times for driver and by 1.73 times for front passenger when there were rear seat occupants. Based on the logit model by Shimamura [3], the number of driver and front passenger fatalities would decrease by 25% and 28%, respectively.

Using in-depth accident data of ITARDA (Institute for Traffic Accident Research and Data Analysis), Shimamura [8] also examined 123 rear-seat unbelted occupants. He classified the behavior of unbelted 101 rear seat occupants whose contact location was identified, into three categories. First is the case where the rear seat occupants are stopped by the seatback of the front seat (82 cases). Second is when the rear seat occupants are thrown over the front seat (6 cases). And third is when the rear seat occupants are moved through either side of the front seats (13 cases). There were several accidents in which the front seat occupants sustained injuries to the chest and abdomen since the rear seat passengers impacted the front seatback and the front seat occupants were compressed by the deformation of the front seatback.

At present, the adult occupants are not positioned in the rear seat in the frontal crash test regulation. For the rear seat, there are no airbags, and many vehicles have only conventional seatbelts without a pretensioner or force limiter. Accordingly, the injury risk to rear seat occupants is likely to be higher than to front seat occupants. Recently, the injury risk to rear occupants has probably been increasing because

the vehicle acceleration is inclined to be high due to the stiff passenger compartment.

The National Highway Traffic Safety Administration (NHTSA) has a research program focusing on rear seat occupant safety [9]. In the research, the Hybrid III AM50 (adult male 50th percentile) and AF05 (adult female 5th percentile) dummies in the rear seat showed larger injury criteria than those in the front seat, especially for HIC15, neck (tension and Nij) and chest deflection. Transport Canada also has a research project dealing with rear seat safety [10]. The Hybrid III AF05, 6YO (year-old) and 3YO were tested, and the Hybrid III AF05 in the rear seat was likely to have a large chest deflection, and depending on the location of seatbelt anchor, the lap belt could intrude into the abdomen.

The seatbelt design method for rear seat occupant safety has been analyzed. Zellmer et al. [11] examined the behavior and injury risk of rear seat occupants based on Hybrid III AM50 test and MADYMO analysis. It was shown that a seatbelt pretensioner and force limiter were effective for reduction of chest loadings, and they proposed that a 6-kN force limiter be used to reduce both chest loadings and head excursion. Kawaguchi et al. [12] tried an optimized design for various size occupants in the rear seat. They concluded that to reduce the injury criteria of various size dummies, a seatbelt force limiter of 3.5 kN and belt outlet of 0-200 mm retractor were useful.

In May 2006, the Council of Transport Policy Council, Road Traffic Working Group in Japan published a report for the future road traffic safety underscoring the need for measures to encourage the use of safety devices among car users in order to reduce the number of traffic fatalities. The use of seatbelts by rear seat occupants is one of the important issues to be tackled, even though widely recognized. The National Agency for Automotive Safety & Victims' Aid (NASVA) conducted a research project for rear seat occupant safety. This paper summarizes the results of crash tests in this NASVA research project to demonstrate the effectiveness of seatbelts for the safety of rear seat occupants.

METHOD

Test Conditions

The effect of a seatbelt in a rear seat was investigated based on crash tests using a crash dummy seated in a rear seat with and without seatbelt. Figure 1 shows the test condition. Two tests (test 1 and 2) were carried out. Full-width rigid barrier tests were conducted at 55 km/h in the same condition as the JNCAP (Japan New Car Assessment Program) test. In a full-width rigid barrier test, since the vehicle acceleration is high and the dummy loading is great, this test is suitable for the evaluation of a restraint system. A compact wagon (curb mass 1220 kg, engine displacement 1498 cc) was used in the test. Three-point seat belts were installed in the rear seat. In both tests, in the rear seat, the Hybrid III AF05 was seated behind the driver seat, and the Hybrid III 3YO dummy behind the front passenger seat. The Hybrid III AF50 was seated in the driver and front passenger seats.

In test 1, the Hybrid AF05 wore a three-point seat belt, and the Hybrid 3YO was restrained in the forward-facing child restraint system (CRS) in the rear seat. In test 2, the Hybrid III AF05 did not wear a seat belt. The Hybrid III 3YO was seated on the CRS without a CRS harness strap restraint, though the CRS was fixed on the rear seat with a seatbelt. Figure 2 shows the seating posture of dummies in the rear seat. In both tests, the Hybrid III AM50 was seated in the driver and passenger seat while wearing a seatbelt. To examine the influence of the rear seat occupants on the injury risk to the front seat occupants, injury criteria of the driver dummy were compared to those in the JNCAP full-width rigid barrier test without rear seat occupants.

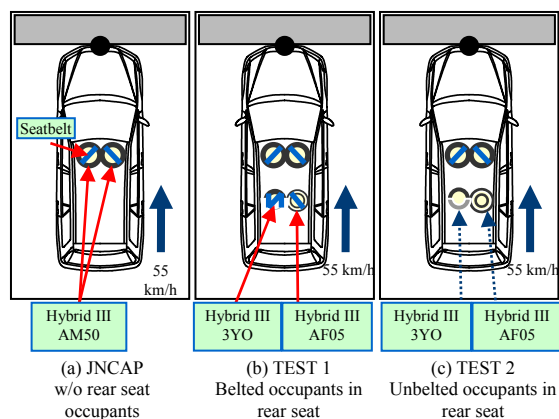


Figure 1. Test conditions.

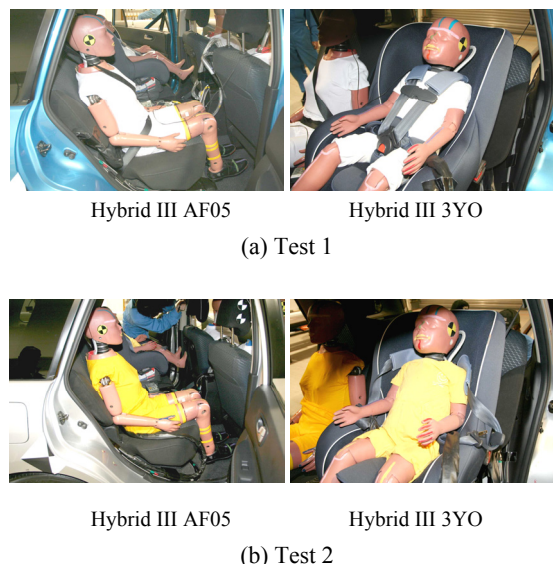


Figure 2. Rear seat dummies in test 1 and 2.

Injury Criteria

Injury criteria of dummies in the rear and front seats were examined. Injury assessment reference values (IARVs) from FMVSS 208, ECE R94 and the literature by Mertz [13] were used. The IARV of chest deflection depends on the loading configuration on the chest. For the unbelted Hybrid III AF05 and 3YO dummies, the IARV of the chest deflection by the distributed load were used from FMVSS 208. The IARV of the distributed load was also used for the Hybrid III 3YO in the CRS because the load on the Hybrid III 3YO chest is likely to be distributed in the 5-point harness CRS. The IARV of chest deflection in the concentrated load due to the shoulder belt was applied from the ECE R94 to the belted AM50 dummy, and the IARV in the literature [13] was applied to the belted AF05 dummy.

The probability of injury was also calculated based on the injury criteria of the crash dummy. Basically, injury risk curves were adopted from those used in the JNCAP to calculate scores. The injury risk curve of the head was from Mertz et al. [13], and that of the chest and the femur was according to Viano and Arepally [14]. For unbelted occupants, the risk curve of the chest injury due to the distributed load was from Mertz et al. [13]. To calculate the probability of injury for AF05 and 3YO from that of AM50, their scale factors indicated by Mertz et al. [13] were used.

RESULTS

Car Deformation and Acceleration

Figure 3 presents photos of the deformed cars after crash. The passenger compartment was intact, and the intrusion was small. The acceleration-time histories are shown in Figure 4. Since the vehicle deceleration in JNCAP, test 1 and test 2 were similar, the inertial loads applied to the occupants are likely to be similar in the three tests.

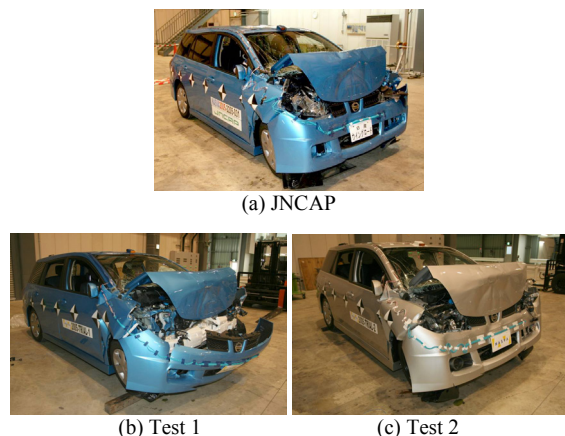


Figure 3. Car deformation.

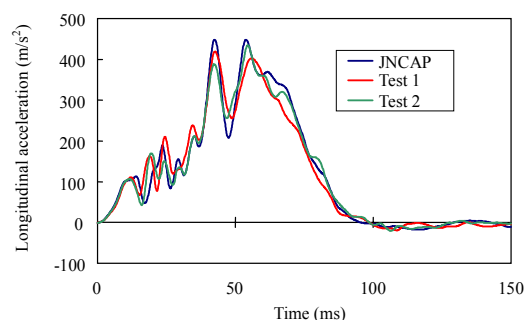


Figure 4. Car acceleration-time histories.

Occupant Kinematics

Test 1 (belted rear seat occupants)

The behavior of belted-in occupants is restrained during impact. Figures 5 and 6 present the behavior and readings for the dummies in the rear seat. Under the restraint of the seatbelt, the torso and neck of both dummies flexed. The chest acceleration of the AF05 has a maximum value at 65 ms, although no contact of the dummy with the car interior was observed from a high-speed video. The head accelerations and excursions of both dummies are maximal at 88 ms and at 102 ms, respectively. The chin made contact with the sternum (105 ms), which led to high head acceleration, especially for 3YO. In the rebound

phase, both dummies moved backward in the initial seated position (1000 ms). Since the Hybrid III AF05 was restrained by the seatbelt, the head contacted neither the vehicle interior nor the front seat dummies. The Hybrid III 3YO in the CRS also did not make contact with the car interior, except for the contact between the feet and the seatback. Judging from the kinematics of the lower extremities, the impact force is probably small.

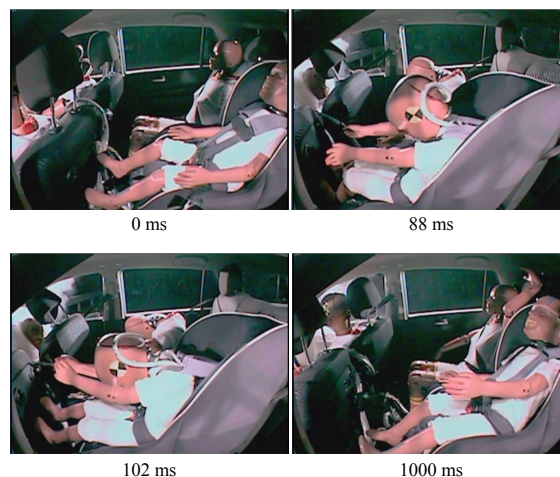
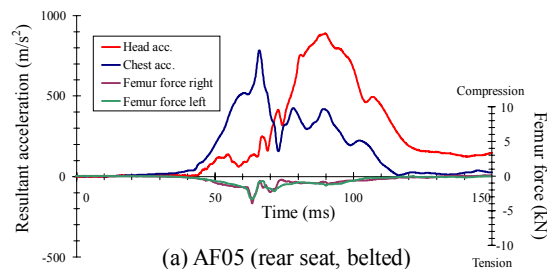
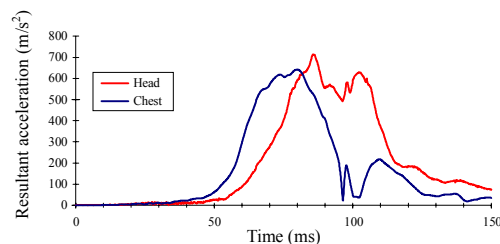


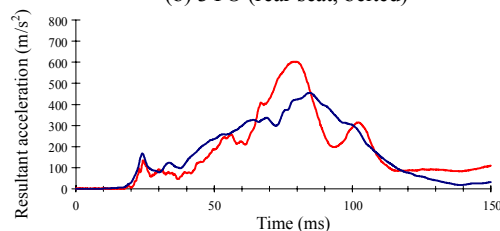
Figure 5. Kinematics of belted dummies in rear seat (test 1).



(a) AF05 (rear seat, belted)



(b) 3YO (rear seat, belted)



(c) AM50 (driver, belted)

Figure 6. Dummy readings in test 1.

Test 2 (unbelted rear seat occupants)

Because the rear seat occupants were not restrained, they moved forward under impact. Occupant movement was decelerated by impact with several locations in the car interior until the occupant moved with the same velocity as the car. Figures 7 and 8 show the unbelted occupant kinematics in the rear seat. Figure 9 plots the acceleration of the dummies.

The Hybrid III AF05 dummy moved forward in the initial seated posture. Its knees made contact with the front seatback (70 ms), and the femur force and pelvis acceleration were maximal (86 ms). The upper body started to rotate around the knee in the forward direction (100 ms), then was thrown over the front seat. The chest made contact with the seatback, and the face of the Hybrid III AF05 hit the pole of the head restraint at 47 km/h (120 ms). The Hybrid III AF05 also hit the occipital region of the driver dummy head at 36 km/h (122 ms). The Hybrid III AF05 continued to rotate forward, and the back region and the head hit the roof and the windshield, respectively (192 ms).

The unbelted Hybrid III 3YO also moved forward in the initial seated posture, and the foot soles and knees made contact with the seatback of the front passenger seat at 60 ms and 86 ms, respectively. Then the upper body rotated and was thrown over the front seat. The head traveling velocity was about 44 km/h based on the video analysis. The head hit the roof header at 135 ms, and the back region hit the roof at 170 ms. Its head struck the windshield, and finally dropped on top of the instrument panel at 200 ms.



Figure 7. Kinematics of unbelted Hybrid III AF05 in rear seat (test 2).

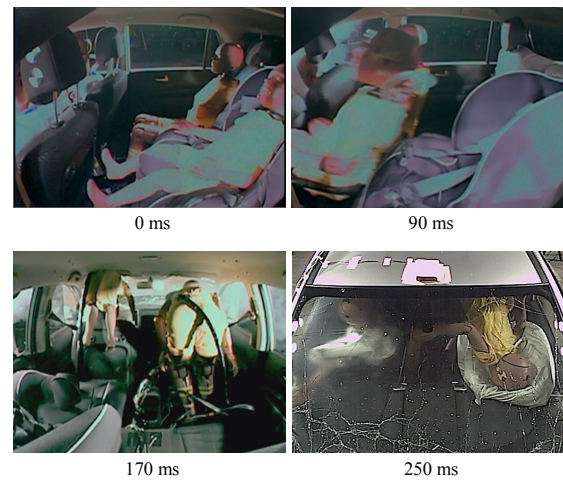


Figure 8. Kinematics of unbelted Hybrid III 3YO in rear seat (test 2).

For the driver dummy, there are peaks in the chest acceleration (90 ms) due to the impact by the rear seat Hybrid III AF05. Energy absorption of the airbag was almost finalized at 125 ms. However, the driver head was impacted from the rear by the face of the rear seat Hybrid III AF05, after which the driver head was thrown against the steering wheel (Figure 7).

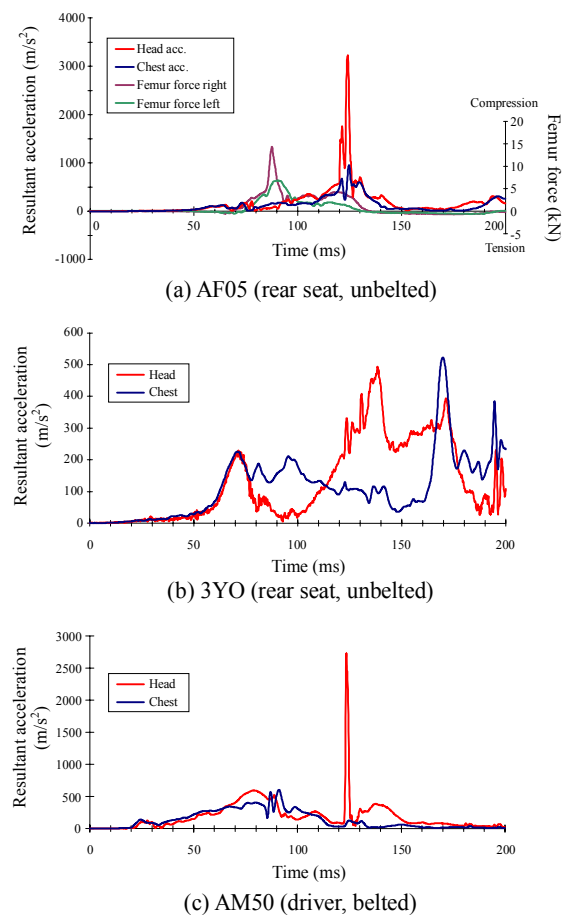


Figure 9. Dummy readings in test 2.

Injury Criteria

Injury criteria of dummies in the rear seat and in the front seat are shown in Tables 1 and 2, respectively. Based on these criteria, the ratio of injury criteria to the IARVs and the probability of injury are shown in Figures 10 and 11.

When the Hybrid III AF05 was belted in the rear seat, the head and chest injury criteria were relatively larger than the IARVs. For the unbelted AF05, the HIC15 and the femur forces were extremely high. Based on the injury criteria, the probability of head injury is 95% for AIS 4+ and that of femur fracture is 99.8%. Thus, serious injuries are very likely to occur.

For the belted Hybrid III 3YO, the injury criteria of head and chest were less than IARVs. The HIC15 and chest deflection of the unbelted Hybrid III 3YO were far less than IARVs. The chest acceleration (3 ms clip) took a maximum value of 470 m/s^2 when the back region of the Hybrid III 3YO made contact with the roof (see Figure 9), though this value was also less than the 539 m/s^2 prescribed in the FMVSS 208.

The injury criteria of the driver dummies in the JNCAP and in the test 1 are similar, which indicates that the belted rear-seat occupants have little influence on the injury criteria of the dummies in the front seat. When the Hybrid III AF05 in the rear seat was not belted, the HIC15 of the driver dummy exceeded the IARV due to impact by the AF05 head. In this case, the chest of the driver dummy was compressed, and chest deflection of the driver dummy was also larger than in other tests, because the front seatback was struck by the impact of the rear-seat Hybrid III AF05.

Table 1. Injury criteria (rear seat dummies)

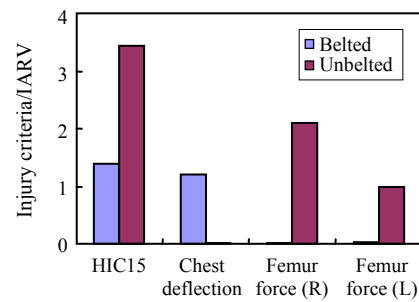
	Rear seat AF05		Rear seat 3YO	
	Belted (Test 1)	Unbelted (Test 2)	Belted (Test 1)	Unbelted (Test 2)
HIC15 ⁽¹⁾	972 (700*)	2403 (700*)	466 (570*)	138 (570*)
Chest deflection (mm)	49.5 (41**)	1.0 (52*)	25.2 (34*)	6.6 (34*)
Femur force right (kN)	0.1 (6.8*)	14.3 (6.8*)	NA	NA
Femur force left (kN)	0.2 (6.8*)	6.8 (6.8*)	NA	NA

Parentheses show injury reference values from * FMVSS 208 and **Mertz et al. [13].

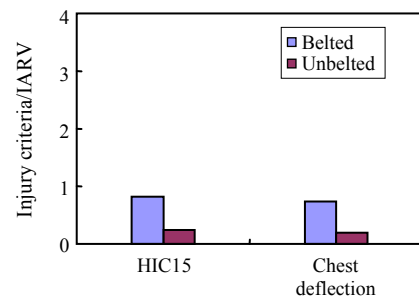
Table 2. Injury criteria (driver dummy)

Rear seat dummy	Belted driver dummy (AM50)		
	No dummy (JNCAP)	Belted AF05 (Test 1)	Unbelted AF05 (Test 2)
HIC15	358 (700*)	344 (700*)	1218 (700*)
Chest deflection (mm)	27.2 (50**)	25.8 (50**)	29.2 (50**)
Femur force right (kN)	0.3 (10.0*)	0.4 (10.0*)	0.4 (10.0*)
Femur force left (kN)	1.8 (10.0*)	1.7 (10.0*)	1.6 (10.0*)

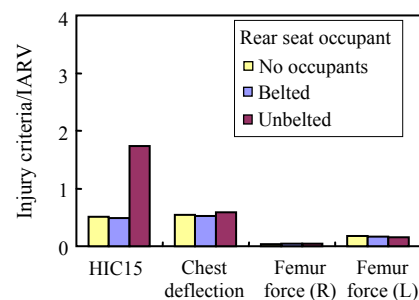
Parentheses show injury reference values from *FMVSS 208 and **ECE R94.



(a) Rear AF05



(b) Rear 3YO



(c) Driver AM50

Figure 10. Ratio of injury criteria to IARVs.

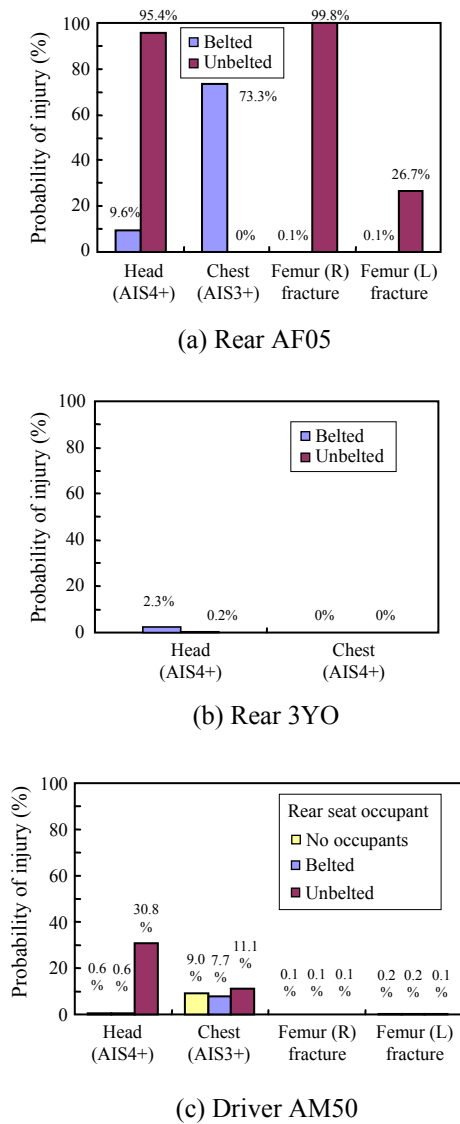


Figure 11. Probability of injury calculated based on IARVs.

DISCUSSION

In test 2, the unbelted Hybrid III AF05 and 3YO in the rear seat were thrown over the front seat. The Ministry of Land, Infrastructure and Transport, Japan conducted a full-width rigid barrier test with two unrestrained Hybrid III AM50 dummies in the rear seat [15]. In the test, the Hybrid III AM50 in the rear seat collided against the seatback of the front seat and rebounded into the rear seat. JAF also conducted offset frontal impact tests with the Hybrid III AF05 and 3YO in the rear seat under conditions similar to those used in test 1 and 2. The Hybrid III

3YO moved in between the driver seat and the front passenger seat. Based on the in-depth accident analysis by Shimamura [3], 81% of the unbelted rear-seat occupants were stopped by the front seat, and 19% were thrown over the front seat. In this accident data, many low velocity accidents were probably included, which made for the high frequency with which rear seat occupants returned to their original position after collision. Therefore, the behavior of the unbelted rear-seat dummy varies with its body size, impact velocity and impact force direction. Depending on the collision situation, an unbelted occupant can even be ejected from the passenger compartment.

The HIC15 and chest deflection of the belted Hybrid III AF05 exceeded the IARVs, though there were no significant contacts between the dummy and the car interior. It is not clear whether the HIC15 can be applied to assess the head injury to rear seat occupants when there is no hard head contact. The chest acceleration of belted Hybrid III AF05 was also high in the initial phase before flexion of torso occurred (see Figure 6), though the force path for this high acceleration is not clear. Even though the injury criteria were relatively high for the belted AF05, the safety effectiveness of the seatbelt for the rear occupant injury risk is clear. The injury criteria of unbelted AF05 in the rear seat were extremely high due to contact with several locations in light of the uncontrolled behavior.

The unbelted Hybrid III 3YO was thrown around inside the passenger compartment, and gradually decelerated by impact with several locations. Surprisingly, all measured injury criteria were less than IARVs. However, it is difficult to say that the injury risks of the unbelted Hybrid III 3YO were small based on this test since various body regions of the Hybrid III 3YO made contact with the interior of the car, and the injury risks were difficult to determine.

It was demonstrated that the injury to the front seat occupant could be affected by the unbelted occupants in the rear seat. Under the rear occupant impact into the seatback of the front seat, the chest acceleration and chest deflection of the front seat occupant can become large. It is not clear that such great injury criteria really reflect injury risks to front seat occupants from the rear impact because of the

Hybrid III limitation. However, accident analysis has demonstrated that the injury risks to front occupants increase when there are unbelted rear-seat occupants [3,6,7,8].

The kinematics and injury criteria of the dummy in the rear seat were probably affected by various factors such as car acceleration, initial posture, and the size and properties of dummies. Further investigation of the safety of the rear-seat occupants is warranted taking into account the various sizes of rear seat occupants.

CONCLUSIONS

The Hybrid III AF05 and 3YO dummies were seated in the rear seat in the belted or unbelted condition, and full-width rigid barrier tests were carried out at 55 km/h. The conclusions may be summarized as follows:

1. The injury risk was low for the belted AF05 in the rear seat because the contact with the car interior was prevented by the seatbelt, though the chest deflection was large by the shoulder belt. When the AF05 was not belted, risks of head injury and femur fracture were particularly high due to contact with several locations in the car interior.
2. When the Hybrid III 3YO was restrained by the CRS, the only contact with the car interior was between the feet and front seatback. The unbelted Hybrid III 3YO was thrown over the front seat, making contact with the front seat, roof and instrument panel.
3. When the Hybrid III AF05 in the rear seat was belted in, the AF05 did not affect the driver dummy behavior. However, the unbelted AF05 made contact with the rear seatback and the driver head, which could result in severe injuries to the head and chest of the driver dummy.

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