

A Study of the Rear Seat Occupant Safety using a 10-Year-Old Child Dummy in the New Car Assessment Program

Seong-Woo Hong, Chung-Kyu Park, Richard M. Morgan and Cing-Dao Kan

The George Washington University

Shinhee Park and Hanil Bae

Hyundai-Kia Motors

Copyright © 2008 SAE International

ABSTRACT

The National Highway Traffic Safety Administration (NHTSA) conducted a total of 28 frontal crashes in the New Car Assessment Program (NCAP) involving the 10-year-old child Hybrid III dummy. The 10-year-old child dummy was in the rear seat. All types of vehicles (passenger cars, sport utility vehicles, vans and pick-up trucks) were tested to assess the effect of restraint systems such as booster and pretensioner on the rear seat occupant. In this study, the readings of the 10-year-old child dummy in rear-left and rear-right seat positions are examined.

The authors apply a possible 5 star rating system, based on head and chest readings of the 10-year-old dummy. The paper also assesses the safety performance of rear seat occupants and the effect of the restraint systems on a child in the rear seat. This paper suggests that a star rating for rear seat occupants is independent of the present ratings for the driver and front adult passenger in NCAP.

This study examines the dynamic signals of the vehicle and the child dummy in the 28 NCAP crashes. The examination figured out the relationship between vehicle pulse and dummy pulse compared with 5-4 star-rated vehicles or 3-1 star-rated vehicles based on the rear seat occupant responses. The child dummy signals are compared for different passenger vehicles. For example, the comparison of high head acceleration and low chest acceleration case to low head acceleration and high chest acceleration case is performed for vans.

INTRODUCTION

Recently, several researchers wanted to change the focus of frontal crashworthiness to rear seat occupant protection. By analyzing injury patterns of rear seat occupants in real world crashes they showed elderly occupants in the rear seat in frontal crashes are exposed to higher fatality than those in frontal seat [1-3]. In 2007,

the Japanese New Car Assessment Program (JNCAP) evaluated the protection of the front seat adult dummies against the protection of the rear-seated 5th percentile female Hybrid III dummy (roughly the size of a 12-year-old child) [4]. Their research used full-width rigid barrier crashes under the same conditions as JNCAP. The 5th percentile female dummy was restrained by the three-point belt in the rear seat. They found the front seat adults were well under the Injury Assessment Reference Values (IARV) for both head and chest. In contrast, the 5th percentile female dummy was well over the IARV for both head and chest. In addition to the importance of the rear seat occupant safety, the NHTSA recommends children should be seated in the rear seat for the safety. Therefore, the importance of children's safety in rear seat should be emphasized.

Development of the 10-year-old child Hybrid III dummy was initiated around 2000 by the SAE Hybrid III Dummy Design Committee. In addition, the Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act mandated NHTSA to consider a 10-year-old sized dummy in the child restraint improvement portion of the Act. In December 2002, Anton's Law mandated NHTSA to incorporate a 10-year-old dummy into Part 572 by December 2005. The 10-year-old (10YO) child Hybrid III dummy has shoulders with a more realistic shape, and an adjustable lumbar angle to simulate the slouch posture in children. An evaluation of the 10-year-old dummy has recently been completed [5-8].

Injury criteria and Injury Assessment Reference Values (IARV) for FMVSS No. 213 and FMVSS No. 208 of the 10-year-old dummy were proposed by the NHTSA in 2004 (for completeness, these values are summarized in Appendix A) [9-10]. Injury risk function curves for head and chest injury of occupants derived based on the probability of AIS 4+ head or chest injury. A combined probability of head and chest injury is defined for 5 Star rating for 10-year-old child dummy (see Appendix B for details).

ANALYSIS OF 10YO DUMMY IN NCAP TESTS

The NHTSA conducted a total of 28 cases in NCAP with the Hybrid III 10-year-old dummy in the rear seat [11]. These tests were done with various vehicles: 9 passenger cars, 4 sport utility vehicles, 6 vans and 3 pick-up trucks. The 10-year-old child dummy was seated in boosters in the left or right side seat in some tests. One vehicle had rear seat pretensioners.

The star rating of a vehicle is determined by two injury criteria: Head and chest injuries. All the vehicles were rated according to the criteria shown in Figure 1. Factors such as crash pulse, relative velocity and seat belt force that influence HIC_{15} and 3ms clip chest acceleration are focused on in this research.

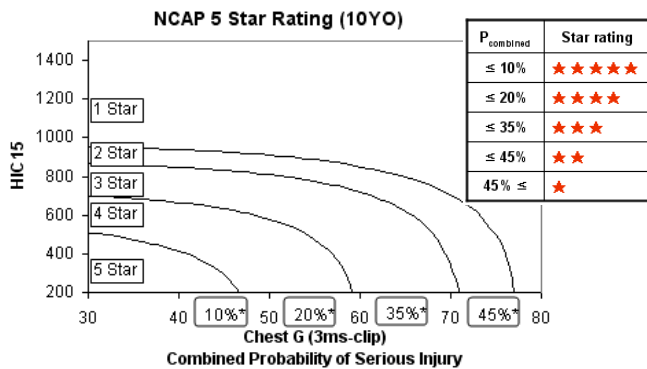


Figure 1. Possible NCAP 5 Star Rating System for 10-year-old Child Occupants in Rear Seat

METHODOLOGY

The vehicle crash pulse is the safety characteristic of the vehicle structure that mainly causes head acceleration. Especially, a rear seat occupant without a frontal air bag is likely to be influenced by the crash pulse directly. The maximum value of the crash pulse during the crash influenced HIC_{15} of the child dummies in the rear seat as shown in Figure 2(a). But Figure 2(b) presents that HIC_{15} is not related to the time when the maximum of crash pulse occurred.

However, Figure 3(a) suggests most HIC_{15} values occurred at 70-80 ms in 3-1 star-rated vehicles and 60-100ms in 5-4 star-rated vehicles. To find out the correlation of the time when HIC_{15} occurred with the crash pulse, the head acceleration curves and the crash pulses were examined. Generally, head acceleration of a rear seat occupant starts to increase at about 30 ms and becomes a bell-shaped curve. Based on this fact, the maximum values of crash pulse during 30-100ms were examined excluding the maximum during 0-30ms. The result presents HIC_{15} are related to the maximum crash pulse during 30-100ms as shown in Figure 3(b).

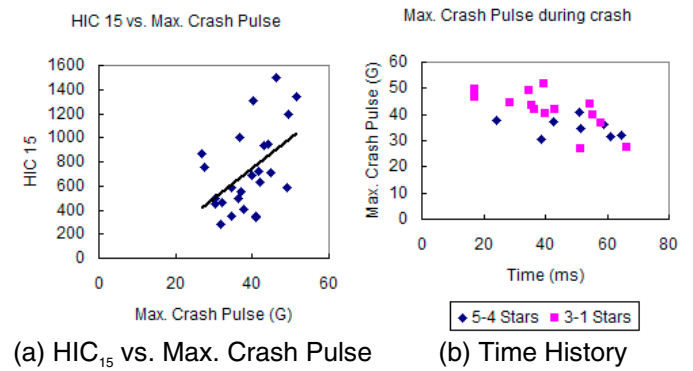


Figure 2. Maximum Crash Pulse during the crash

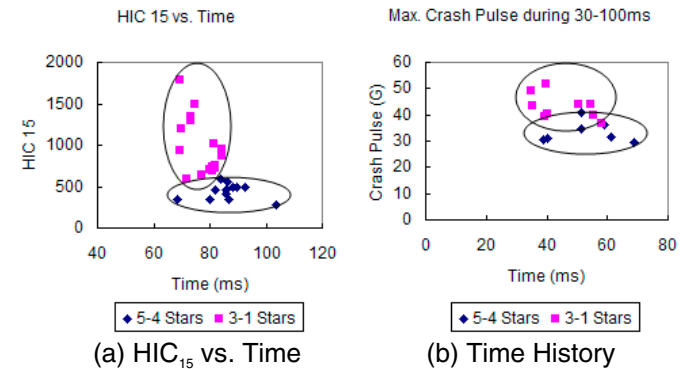


Figure 3. Maximum Crash Pulse during 30-100ms

Relative velocity (V_{rel}) between a dummy's chest and the vehicle is related to chest acceleration. Relative velocity is indicative of an interaction between the crash pulse and belt restraint commonly referred to as "ride down" [12]. Relative velocity is calculated using Equation 1 and determined by the restraint system. V_{chest} is the velocity of a dummy's chest and $V_{vehicle}$ is the integration of the vehicle's acceleration.

$$V_{rel} = V_{Chest} - V_{Vehicle} \quad (1)$$

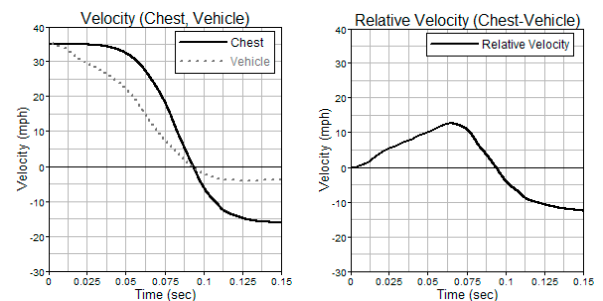


Figure 4. Relative Velocity between Dummy Chest and Vehicle

In a velocity-versus-time diagram [12], a rear seat occupant undergoes a constant velocity and is then sudden acceleration by the force of a restraint system. A dummy rebounds when relative velocity becomes zero as shown in Figure 4. The slope of V_{rel} from 0 ms to the peak time and the maximum value of V_{rel} are the dummy readings around the chest. Figure 5 presents the

relationship between the slope and the maximum value of V_{rel} versus the 3ms clip chest acceleration. A lower slope or lower peak value of V_{rel} represents the lower chest acceleration.

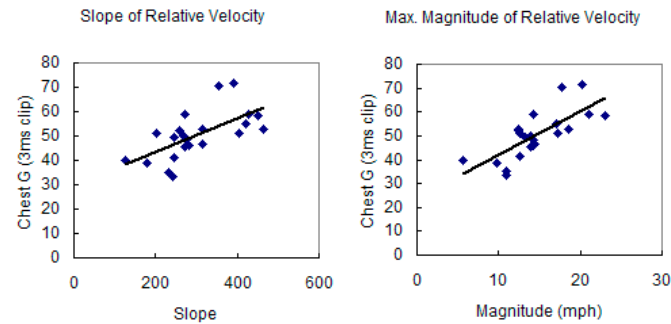


Figure 5. Chest Acceleration (3ms clip) Distribution with the Properties of Relative Velocity (Slop, Maximum Magnitude)

Seat belt force is a characteristic of the restraint system. Seat belt force measured during the crash can be determined by seat belt material, type of retractor, and so on. As shown in Figure 6, chest acceleration is proportional to seat belt force.

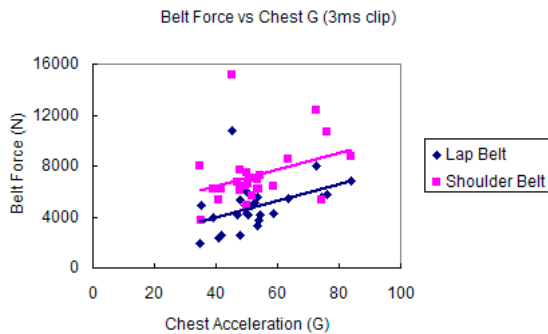


Figure 6. Chest Acceleration (3ms clip) and Seat Belt Force

Both the relative velocity (V_{rel}) between a dummy's chest and a vehicle and the seat belt force were examined to explain the chest reading in the dummy. Not only the relative velocity but also the belt force exerted on the chest can indicate the potential for chest injuries together.

ANALYSIS OF 10YO DUMMY IN PASSENGER CARS

Nine passenger cars (Table 1) were tested in NCAP with the 10-year-old dummy in the rear seat. These 9 tests were evaluated with a possible star rating as shown in Figure 7. Seven out of 9 passenger cars are rated 3-1 stars. With respect to the adult occupants, most of these vehicles were 5 star-rated for both the driver and front passenger [13].

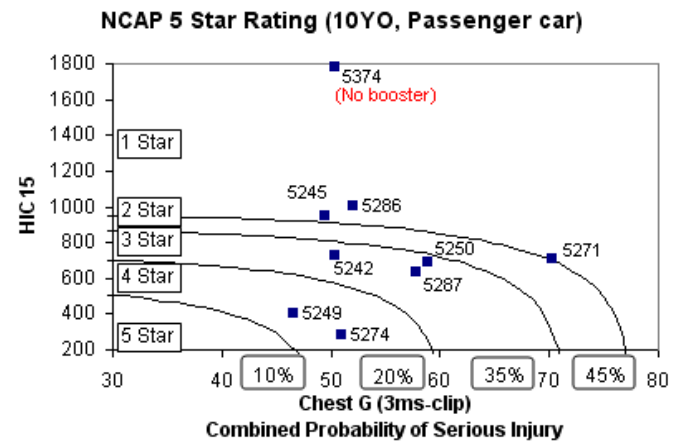


Figure 7. NCAP 5 Star Rating for Rear Seat Occupants (Passenger Car)

Table 1. 10YO Child Dummy Response in NCAP (Passenger Car)

Test No.	Vehicle Information		Front Seat Star Rating		Rear Seat Star Rating (10YO Child Dummy)		
	Maker	Model	Driver	Front Passenger	HIC ₁₅ (<700)	3ms Clip (<60G)	Star rating
5242	Volvo	V70	5 Star	5 Star	725	50	3 Star
5245	Acura	3.5 RL	5 Star	5 Star	951	49	1 Star
5249	Ford	500	5 Star	5 Star	407	47	4 Star
5250	Pontiac	G6	5 Star	4 Star	689	59	3 Star
5271	Chevrolet	Malibu	5 Star	5 Star	705	70	2 Star
5274	Buick	Lacrosse	5 Star	5 Star	286	51	4 Star
5286	Nissan	Maxima	5 Star	4 Star	1008	52	1 Star
5287	Suzuki	Verona	3 Star	4 Star	631	58	3 Star
5374	Volkswagen	Jetta	4 Star	4 Star	*1785	*50	1 Star

It can be concluded that this safety rating for rear seat occupants is independent of the NHTSA rating for the driver or front passenger. As the frontal stiffness of passenger cars becomes stiffer recently, the occupants may experience a more severe crash pulse [14]. The front seat occupants have benefited from advanced restraint systems such as frontal air bags, load-limiters and pretensioners to improve the safety performance (some high-end vehicles are equipped with a pretensioner in the rear seat such as the Mercedes ML350 that is tested in the next section). But the restraint system for a rear seat occupant is almost always a seat belt with retractor. This difference in front seat versus rear seat restraint system leads to difference in safety rating with respect to the occupant position. This tendency is similar to the results of the following study on sport utility vehicles, vans and pick-up trucks. Consequently, the authors suggest a star rating for rear seat occupants would improve vehicle safety.

The Volkswagen Jetta (Test No. 5374) is the only passenger car in which a dummy was seated without a booster. This vehicle was the worst performer (1 star) for rear seat occupants. Figure 8 shows the dummy readings in the Volkswagen Jetta without booster case. Abnormally, head and chest acceleration were very high and had some spikes while seat belt force was normal. Post-crash scene (Figure 9) shows that the dummy's left arm was rotated during the crash may infer the movement of the dummy was not normal. The curve of chest deflection shows it failed to measure the deflection. The dummy's rotation during the crash possibly caused the low reading of the chest deflection.

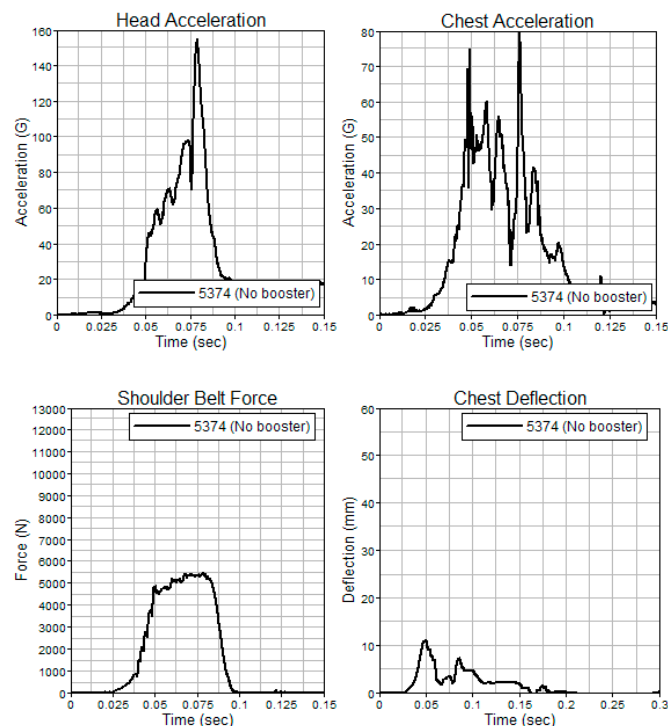
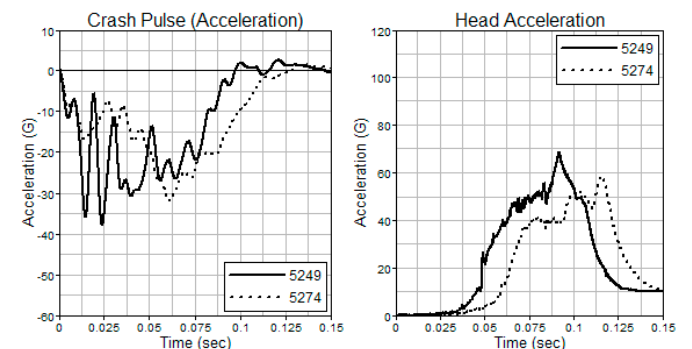


Figure 8. 10-year-old Child Hybrid III Dummy Readings of Volkswagen Jetta without booster

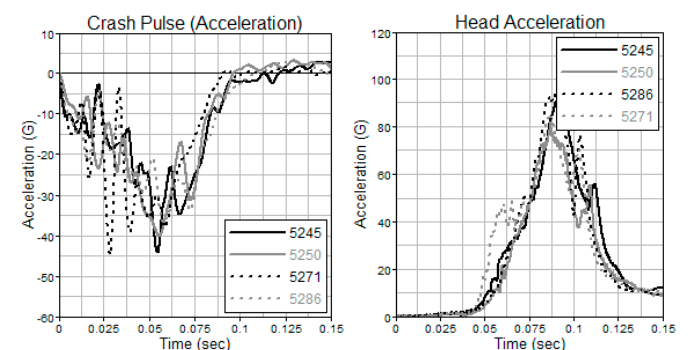
Vehicle safety characteristics and dummy responses in the passenger cars were compared for 5-4 star-rated and 3-1 star-rated vehicles (Figure 10-13). Figure 10 shows how the crash pulse plays an important role on head acceleration. Head acceleration of a dummy in rear seat is influenced by the maximum magnitude of the crash pulse. Generally, the first peak of head acceleration starts around 30ms and ends around 150ms and HIC_{15} occurs in this period. The 5-4 star-rated vehicles have relatively lower peak of crash pulse (Buick Lacrosse, Test No. 5274) or no high peak during 30-100ms (Ford 500, Test No. 5249) while 3-1 star-rated vehicles have high peak in this duration. It can be said that crash pulse can indicate the injury level of a child in rear seat by examining the maximum magnitude of crash pulse during the crash and the peak time during 30-100ms.



Figure 9. 10-year-old Child Hybrid III Dummy without booster in Pre/Post crash (5374)



(a) 5-4 Star Passenger Car



(b) 3-1 Star Passenger Car

Figure 10. NCAP Vehicle Crash Pulse and Head Acceleration of 10YO Dummy (PC)