Safety performance comparisons of different types of child seats in high speed impact tests

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ABSTRACT

Child occupant safety has been evaluated in the European New Car Assessment Program (Euro NCAP) since 2003. Now child protection is being given more and more attention by car manufacturers. To keep up with global developments, China NCAP (CNCAP) has also started conducting child occupant safety assessment in high speed impact tests from Jan. 2010. SAIC Motor company has carried out a series of CNCAP and Euro NCAP tests using several brands of CRSs: 50kph full frontal rigid barrier (FRB) tests, 64kph offset deformable barrier (ODB) tests, and 50kph moving deformable barrier (MDB) side impact tests. In this paper, safety performance of different types of CRSs were compared on the basis of the test results. Child dummy kinematics and responses were influenced by both the vehicle crash pulse and the safety performance of the CRS itself. The injury assessment values for P3 on the barrier overlap side in the 64kph ODB tests were generally lower than those in the 50kph FRB tests. In front impact tests, the vehicle crash pulse had much more influence on the head acceleration than the chest acceleration, while the chest acceleration was more dependent on the CRS internal restraint system. In the side impact test, the P1.5 head of the struck side was contained within the boundary of the CRS shell during the entire crash event. The head accelerations for both P1.5 and P3 dummies in the side impact test were all much better than the threshold value indicated for better performance in Euro NCAP testing.

INTRODUCTION

The main function of earlier CRSs (Child restraint systems) was to contain child occupants, without much attention being paid to providing good protection to CRS occupants in accidents. The first regulation that was issued in 1971 specifically for child restraint system was Federal Motor Vehicle Safety Standard (FMVSS) 213 in the United States. That was followed in 1982 by the European regulation ECE R44 [1]. CRSs which are approved through these regulations afford good protection to children in accidents.

There are many types of CRSs suitable for different age groups of children. According to different installation methods for a CRS in a vehicle, a CRS which can be installed by using a vehicle seat belt is called a universal CRS, while a CRS which can be installed by using an ISOFIX (International Organization for Standardization, FIX) anchorages system is called an ISOFIX CRS.

Front 64kph ODB test and side 50kph MDB test are the two tests in which TNO P-series dummies P3 (3 years old) and P1.5 (1.5 years old) are positioned in the vehicle outboard rear seats in Euro NCAP testing. CNCAP introduced child safety assessment in full frontal 50kph FRB test from Jan. 2010. For the CNCAP 50kph FRB test, P3 is positioned in the vehicle outboard rear seat, and in the opposite side a Hybrid III 5%ile female dummy is positioned.

SAIC Motor has carried out a series of tests according to Euro NCAP and CNCAP protocols. In this study, test data was collected from 8 FRB tests, 2 ODB tests, and 1 MDB test using different CRSs in different cars. By comparing the child dummy kinematics and responses – head and chest accelerations, head forward excursion in front impact tests, and head containment in side impact test, the safety performances of different CRSs were assessed.

METHOD

Frontal 50kph FRB tests

CNCAP assesses the child occupant safety by using a P3 dummy in 50kph FRB tests. Three brands of CRSs were used in eight 50kph FRB tests for the vehicles manufactured by SAIC Motor, listed in Tabel 1. Vehicles A to D were all passenger cars, Vehicle D being a compact car. Vehicle E was an SUV. Vehicles A and B had ISOFIX anchorage systems in the outboard rear seats, and others did not. Four distinctly different installation methods as specified in Table 1 were used for installing the CRSs to vehicles. CRS 1 (Figure 1) used in Tests 01 and 02 was installed by ISOFIX and support leg. CRS 2 (Figure 2) used in Tests 03, 04, and 05 was installed by vehicle 3-point seatbelt. CRS 3-1 (Figure 3) used in Test 06 was installed by LATCH (Lower Anchorage and Tether for Children), while CRS 3-2 (Figure 4) used in Tests 07 and 08 was installed by vehicle 3-point seatbelt. CRSs 1 and 2 were internal 5-point harness type. CRSs 3-1 and 3-2 were impact-shield type. In all the tests listed in Table 1, P3 dummy was restrained in the CRSs and was positioned in the vehicle right-side rear seat.

Table 1.
Frontal 50kph FRB test matrix

Test No.	Vehicle	CRS	CRS installation method
01	A	CRS 1	ISOFIX and support leg
02	B	CRS 1	ISOFIX and support leg
03	C	CRS 2	vehicle 3-point seatbelt
04	D	CRS 2	vehicle 3-point seatbelt
05	E	CRS 2	vehicle 3-point seatbelt
06	B	CRS 3-1	impact-shield type, installed by LATCH
07	C	CRS 3-2	impact-shield type, installed by vehicle 3-point seatbelt
08	D	CRS 3-2	impact-shield type, installed by vehicle 3-point seatbelt

Figure 1. CRS 1 in Tests 01 and 02 (50kph FRB)

Figure 2. CRS 2 in Tests 03, 04, and 05 (50kph FRB)

Figure 3. CRS 3-1 in Test 06 (50kph FRB)

Figure 4. CRS 3-2 in Tests 07, 08 (50kph FRB)

Frontal 64kph ODB tests

Euro NCAP assesses the child occupant safety by using both P3 and P1.5 dummies in 64kph ODB tests. P3 and P1.5 restrained by CRSs are positioned on the vehicle outboard rear seats behind the driver side and the front passenger side respectively. Two brands of CRSs were used in two 64kph ODB tests for Vehicles A and B, listed in Table 2. Vehicles A and B were the same types of Vehicles A and B listed in Table 1. Vehicle A was a left-hand drive passenger car, and Vehicle B was a right-hand drive passenger car.

Table 2.
Frontal 64kph ODB test matrix

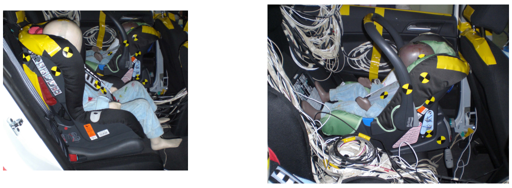
Test No.	Vehicle	CRS	CRS installation method
01	A	CRS 1-P3	Forward-facing, ISOFIX and support leg
		CRS 1-P1.5	Rearward-facing, ISOFIX and support leg
02	B	CRS 2-P3	Forward-facing, ISOFIX and top tether
		CRS 2-P1.5	Rearward-facing, ISOFIX and support leg

CRS 1-P3 was a CRS installed by a forward-facing ISOFIX base with a support leg (Figure 5a), while CRS 1-P1.5 was a CRS installed by a rearward-facing ISOFIX base with a support leg

(Figure 5b). CRS 2-P3 was a forward-facing CRS with ISOFIX and top tether for installation (Figure 6a), while CRS 2-P1.5 was a rearward-facing CRS with ISOFIX and support leg for installation (Figure 6b).

(a) Forward-facing CRS 1-P3 (b) Rearward-facing CRS 1-P1.5

Figure 5. CRSs 1-P3 and 1-P1.5 in Test 01 (left-hand drive passenger car) (64kph ODB)



(a) Forward-facing CRS 2-P3 (b) Rearward-facing CRS 2-P1.5

Figure 6. CRSs 2-P3 and 2-P1.5 in Test 02 (right-hand drive passenger car) (64kph ODB)

Side 50kph MDB test

Euro NCAP also assesses the child occupant safety by using both P3 and P1.5 dummies in side 50kph MDB tests. P1.5 and P3 restrained by CRSs are positioned on the vehicle rear seat behind the driver side and the front passenger side respectively. P1.5 is on the struck side. Two CRSs were used in the 50kph MDB test for Vehicle A, given in Tabel 3. Figure 7 shows the positions of the CRSs and dummies before the test. The CRS shown in Figure 7 was the same brand of CRS used in the 64kph ODB Test 01 shown in Figure 5.

Tabel 3.
Side 50kph MDB test matrix

Test No.	Vehicle	CRS	CRS installation method
01	A	CRS 1-P1.5	Rearward-facing, ISOFIX and support leg
		CRS 1-P3	Forward-facing, ISOFIX and support leg

(a) CRS 1-P1.5 (b) CRS 1-P3

Figure 7. CRSs 1-P1.5 and 1-P3 in Test 01 (50kph MDB)

The instrumentations of the P3 and P1.5 used in the tests listed in Tables 1, 2, and 3 included head and chest uniaxial accelerometers. Electronic data was sampled at 10,000 samples/sec and was filtered at SAE J211 prescribed filter classes.

RESULTS

Frontal 50kph FRB tests

The right side B pillar base x decelerations in all the tests listed in Table 1 are shown in Figure 8. It can be found that the B pillar base decelerations for the passenger cars A (Test 01), B (Tests 02 and 06), and C (Tests 03 and 07) were similar. However, for the compact passenger car D (Tests 04 and 08) the deceleration started at a faster rate, peaking and decreasing earlier than the other cars. This is because Car D was a smaller car and the engine compartment was shorter than the other cars. The deceleration for the SUV E (Test 05) started later, and peaked later than the other cars, since it had a larger engine compartment than the other cars.

The head resultant, chest resultant and z accelerations are shown in Figures 9, 10, and 11. The chest accelerated earlier than the head in each test, since the CRS harness strap or the front shield restrained the chest, while the restraint loads were transferred from the torso through the neck to the head.

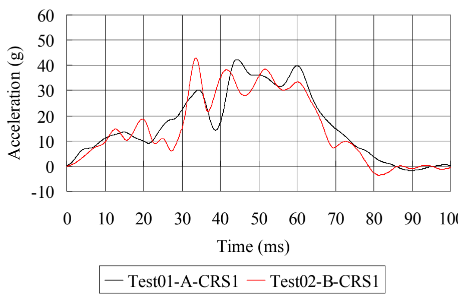
From Figures 9a, 10a, and 11a, it was found that the head and chest accelerations in Tests 01 and 02 were similar, because the same type of CRSs were used in these two tests and the vehicle crash pulses in these two tests were similar (Figure 8a). A plateau before the peak appeared in the chest accelerations in Tests 01 and 02 (Figure 10a). This is because the child seat back made a large forward movement during the tests (Figure 12), which limited the load applied by the child seat harness strap to the chest. The head accelerations in Tests 01 and 02 were high, due to the head contacting the vehicle front seat back (Figure 12) (by noting the red grease paint).

Although the same type of CRSs were used in Tests 03, 04, and 05, however the vehicle crash pulses of the three tests were different (Figure 8b), the head and chest accelerations were different among the three tests (Figures 9b, 10b, and 11b).

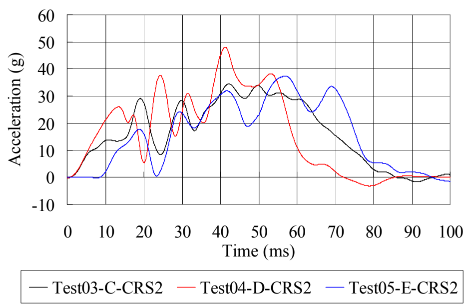
Head and chest accelerations in Tests 06, 07, and 08 are shown in Figures 9c, 10c, and 11c. As the P3 chest accelerometer in Test 06 became loose from its position during the test, and therefore, the chest accelerations in Test 06 were not available and not shown in Figures 10c and 11c. The head accelerations were similar in Tests 06 and 07, with a slightly lower peak in Test 06 than in Test 07, although the CRS in Test 06 was installed by LATCH, while in Test 07 the CRS was installed by vehicle 3-point seatbelt. There appeared a peak in the vehicle crash pulse in Test 08 (Figure 8c), and the head and chest accelerations in Test 08 also had a higher peak than those in Tests 06 and 07.

The chest acceleration in Test 07 decreased slightly at about 50 ms and 60 ms, then increased again (Figure 10c). This was related to the fracture of the impact shield. The impact shield was found to be fractured when it was checked after the test (Figure 13). It can be seen from Figure 14 that the torso in Test 07 bent forward prominently, since P3 was restrained by the front shield and no strap restrained the shoulder. The whole torso made contact with the front shield, and the head made contact with the left arm and leg in Test 07. While in Test 03 only the head bent downwards, and the torso was restrained under the harness strap (Figure 15). The head forward excursion (Figure 14a) seemed to be beyond 550 mm, which was the threshold value used in ECE R44 sled test and 64kph ODB Euro NCAP test.

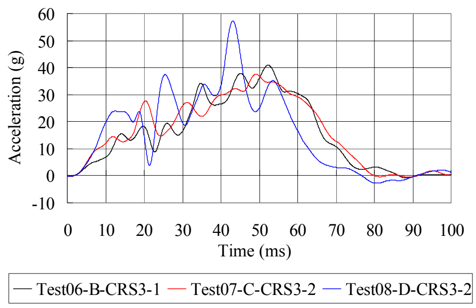
The vehicle 3-point seatbelt forces in Tests 03, 07, and 08 are shown in Figure 16. Both the shoulder belt and lap belt force in Test 08 increased faster than those in Tests 03 and 07, just like the crash pulse of Test 08 increased the earliest (Figure 8c). The time of the belt forces peaks were about 65 ms, which was close to the time of the chest acceleration peaks.



(a) Tests 01 and 02

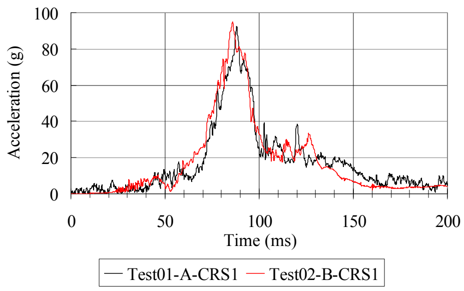


(b) Tests 03, 04, and 05

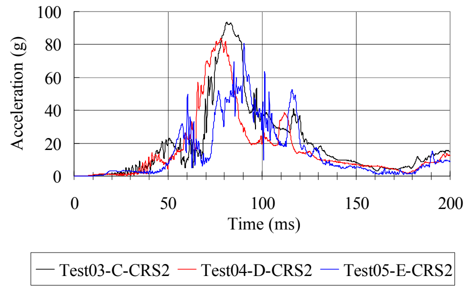


(c) Tests 06, 07, and 08

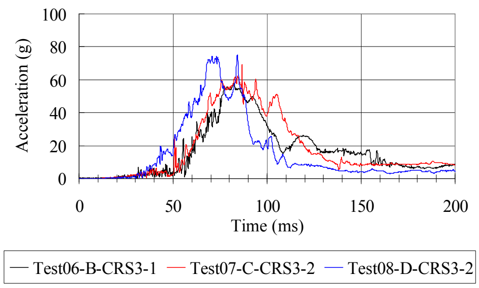
Figure 8. B pillar base x decelerations in Tests 01 to 08 (50kph FRB)



(a) Tests 01 and 02

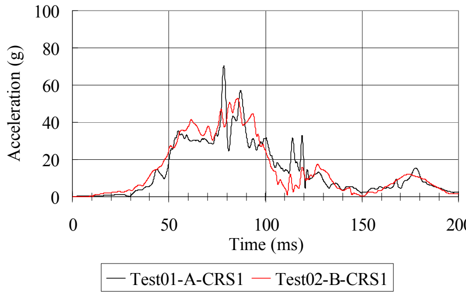


(b) Tests 03, 04, and 05

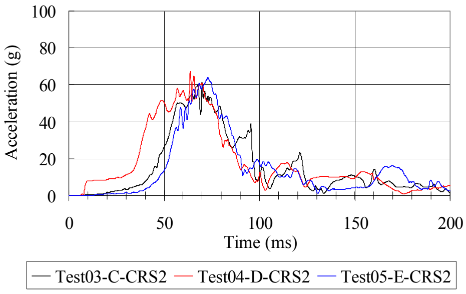


(c) Tests 06, 07, and 08

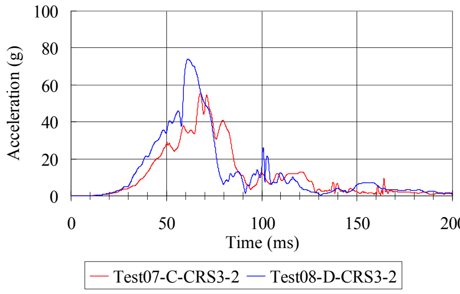
Figure 9. P3 head resultant accelerations in Tests 01 to 08 (50kph FRB)



(a) Tests 01 and 02

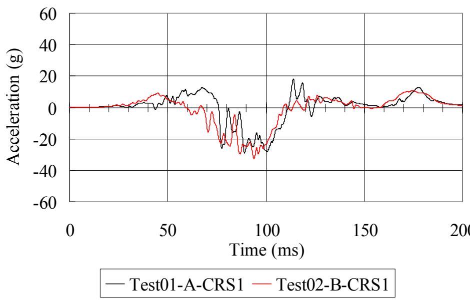


(b) Tests 03, 04, and 05

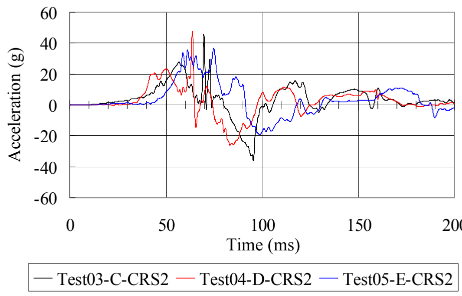


(c) Tests 07, and 08

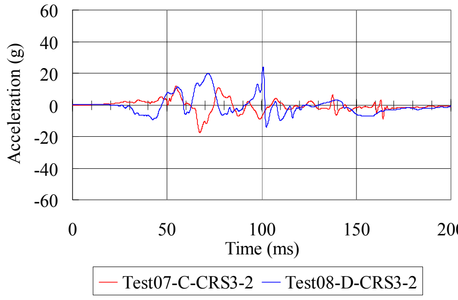
Figure 10. P3 chest resultant accelerations in Tests 01 to 08 (50kph FRB)



(a) Tests 01 and 02



(b) Tests 03, 04, and 05



(c) Tests 06, 07, and 08

Figure 11. P3 chest z accelerations in Tests 01 to 08 (50kph FRB)

Figure 12. Child seat back moved forward excessively and P3 head contacted the front seat back in Test 01 (50kph FRB)

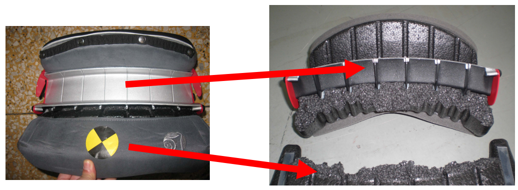
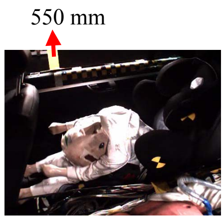


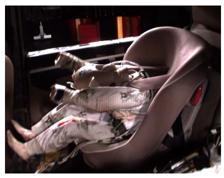
Figure 13. Fractured shield in Test 07 (50kph FRB)



(a) at 100 ms

(b) at 115 ms

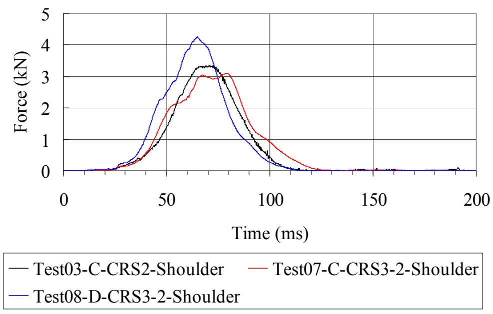
Figure 14. P3 postures at 100 ms and 115 ms in Test 07 (50kph FRB)



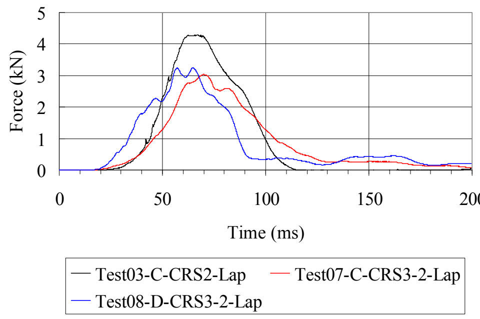
(a) at 100 ms

(b) at 115 ms

Figure 15. P3 postures at 100 ms and 115 ms in Test 03 (50kph FRB)



(a) Shoulder belt forces



(b) Lap belt forces

Figure 16. The vehicle 3-point seatbelt forces in Tests 03, 07, and 08 (50kph FRB)

Frontal 64kph ODB tests

The B-pillar base x decelerations of the driver side in Tests 01 and 02 listed in Table 2 are shown in Figure 17. P3 head resultant, chest resultant and z accelerations in the two tests are shown in Figures 18, 19, and 20. It was found that the P3 head acceleration in Test 02 was much higher than that in Test 01 (Figure 18), while the P3 chest resultant accelerations in the two tests were similar (Figure19). It indicated that the vehicle crash pulse had a much more influence on the head acceleration than the chest acceleration, since the vehicle crash pulse had a much larger peak in Test 02 than in Test 01 (Figure 17), while the chest acceleration was more dependent on the CRS internal restraint system.

There was a peak in the P3 chest z acceleration in Test 02 at around 130 ms (Figure 20). This may have resulted from a position change of the shoulder harness. There were 7 slots for positioning the headrest and the shoulder harness for CRS 2-P3. Before the test, the positioning bar of the shoulder harness was put at the 3rd slot (from top), but after the test, it was found to be at the 4th slot position (from top). The head forward excursion was difficult to judge due to the yaw rotation of the crash car in the test. Figure 21 shows the P3 head posture in the tests. It seemed that the head excursions were not beyond the threshold of 550 mm in both tests.

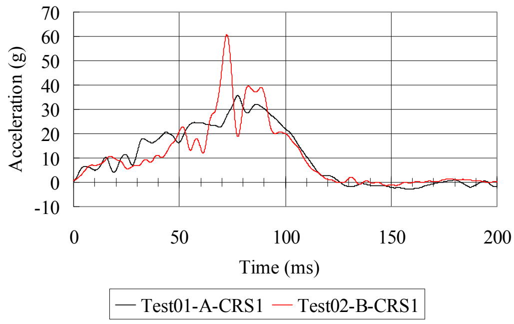


Figure 17. B-pillar base x decelerations in Tests 01 and 02 (64kph ODB)

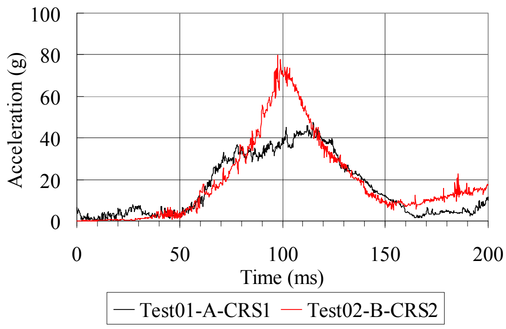


Figure 18. P3 head resultant accelerations in Tests 01 and 02 (64kph ODB)

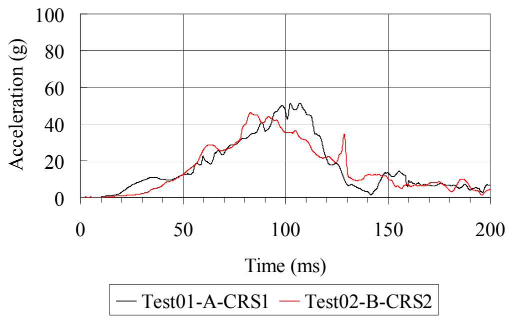


Figure 19. P3 chest resultant accelerations in Tests 01 and 02 (64kph ODB)

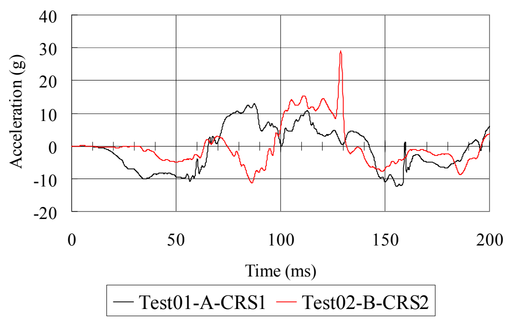


Figure 20. P3 chest z accelerations in Tests 01 and 02 (64kph ODB)

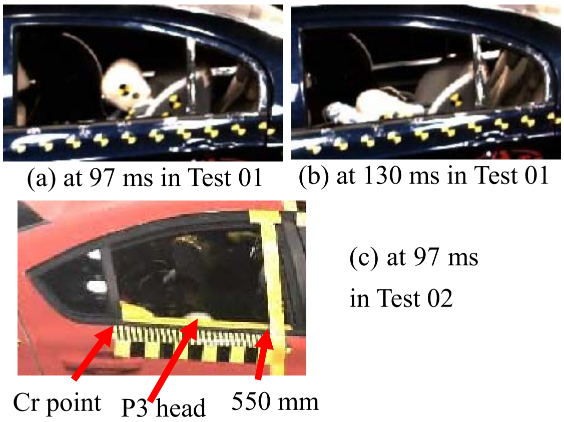


Figure 21. P3 head forward movement in Tests 01 and 02 (64kph ODB)

P1.5 head and chest resultant and z accelerations are shown in Figures 22 to 25. The peak of the head acceleration in Test 02 was higher than that in Test 01 (Figure 22), due to the higher peak of the vehicle crash pulse in Test 02 than that in Test 01 (Figure 17). However, the chest accelerations were similar (Figure 24). This also indicated that the vehicle crash pulse had much more influence on the head acceleration than the chest acceleration, while the chest acceleration was more dependent on the CRS internal restraint system. Head z and chest z accelerations in Test 02 were higher than those in Test 01 (Figures 23 and 25). This was related to the posture of P1.5 in the two CRSs. In Test 02, P1.5 torso was more horizontal than in Test 01 (Figures 5b and 6b). In both tests, the CRS shell upper made contact with the back of the front seat. The force applied by the front seat back was loaded indirectly by the P1.5 through the CRS shell upper.

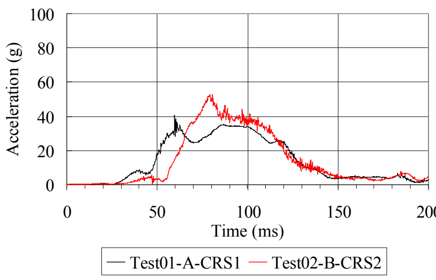


Figure 22. P1.5 head resultant accelerations in Tests 01 and 02 (64kph ODB)

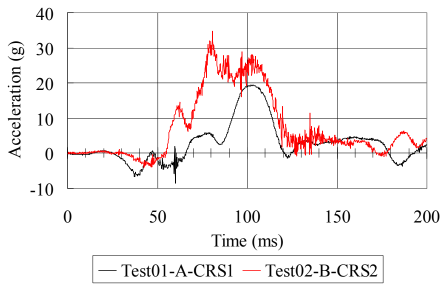


Figure 23. P1.5 head z accelerations in Tests 01 and 02 (64kph ODB)

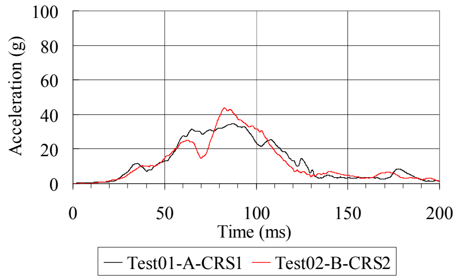


Figure 24. P1.5 chest resultant accelerations in Tests 01 and 02 (64kph ODB)

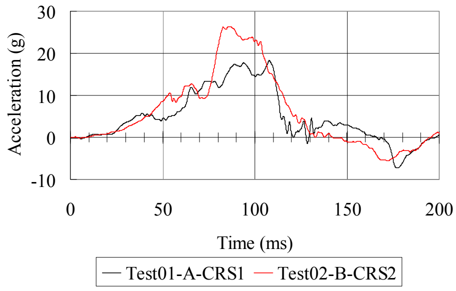


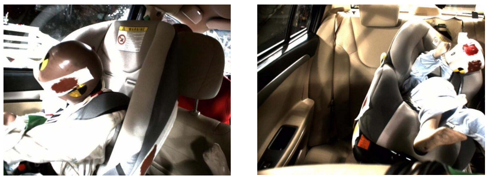
Figure 25. P1.5 chest z accelerations in Tests 01 and 02 (64kph ODB)

Side 50kph MDB test

From the onboard camera film of the side impact test (Test 01 listed in Table 3), the head of the struck-side P1.5 made contact with one side of the CRS shell which was impacted by the door trim panel, then rebounded and contacted the other side of the shell. During this lateral movement, the head was contained within the CRS shell all along (Figure 26a). However for the non-struck-side P3, the CRS rotated laterally toward the struck side under its inertial force, and since there was no support to prohibit this rotation, the CRS rotated around the ISOFIX lower anchorages to a large degree, more than 30 degrees. Thus the P3 head seemed to be partly exposed beyond the edge of the CRS, and not contained completely by the shell (Figure 26b).

From Figure 27 it can be seen that the CRS has contacted the door casing in three places (refer to paint marks). It indicated that the door armrest contacted the base of the CRS 1-P1.5 below the pelvis region (refer to the blue circle), also the door beltline contacted the side wing of the CRS around the shoulder (refer to the yellow circle), making a "bridge" of the contacts. The front of the CRS shell contacted the door trim panel (refer to the green circle). The P1.5 shoulder and chest were indirectly impacted by the door beltline through CRS side wing.

The head and chest resultant accelerations for P1.5 and P3 in Test 01 are shown in Figure 28. It was found that even the head peak accelerations for both P1.5 and P3 were much lower than 72g which is the threshold value indicated for better performance for the head resultant 3ms acceleration used by Euro NCAP [2]. The chest acceleration of P1.5 got a large peak at about 50 ms (Figure 28a), which was indirectly caused by the door beltline area contacting the CRS side wing. The chest acceleration of P3 got a peak at about 85 ms (Figure 28b), which was caused by the rotation of the CRS laterally.



(a) P1.5 at 155ms (b) P3 at 121ms

Figure 26. Head containment for P1.5 and P3 (50kph MDB)

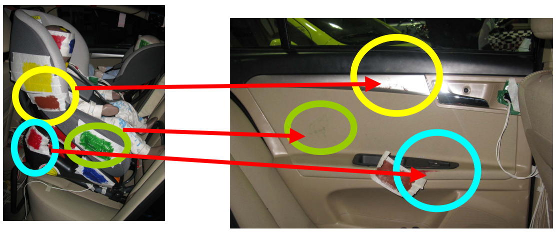
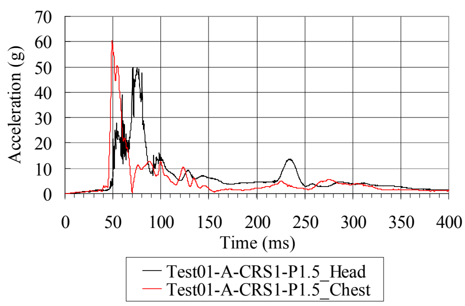
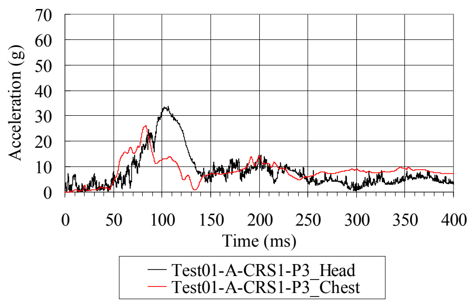


Figure 27. The shell of CRS 1-P1.5 contacting the door casing (50kph MDB)



(a) P1.5 accelerations



(b) P3 accelerations

Figure 28. Head and chest accelerations for P1.5 and P3 (50kph MDB)

Summarization of injury assessment values

Injury assessment values for P3 and P1.5 in the 50kph FRB tests, 64kph ODB tests, and the 50kph MDB test are listed in Table 4. IARV (Injury Assessment Reference Value) of 570 and 1000 were used for HIC15 and HIC36 for P3, respectively. The Euro NCAP limit values of 72g, 41g, and 23g, and limit values of 88g, 55g, and 30g for better performing and worse performing, were used for head and chest resultant cumulative 3ms accelerations, and chest z cumulative 3ms acceleration respectively. The better performance limit value of 20g and the worse performance limit value of 40g were used for P1.5 head z cumulative 3ms acceleration.

Table 4.
Injury assessment values for all the tests

Injury Criteria		HIC15 HIC36 for P3	Head resul. acc. 3ms (g)	Chest resul. acc. 3ms (g)	Chest z acc. 3ms (g)
IARVs		570 / 1000			
Injury Criteria		Head z acc. 3ms (g) for P1.5			
IARVs		Euro NCAP better performance limit			
		20	72	41	23
		Euro NCAP worse performance limit			
		40	88	55	30
Front 50kph FRB tests	Test01-A-CRS1	646	76.7	55.0	26.6
	Test02-B-CRS1	798	86.0	50.1	28.8
	Test03-C-CRS2	971	92.2	56.2	31.2
	Test04-D-CRS2	709	80.9	60.1	25.2
	Test05-E-CRS2	311	60.3	61.1	32.0
	Test06-B-CRS3-1	300	55.0	N/A	N/A
	Test07-C-CRS3-2	362	59.6	51.5	12.2
	Test08-D-CRS3-2	472	72.1	71.4	18.7
Front 64kph ODB tests	Test01-A-CRS1-P3	171	43.2	50	12.2
	Test02-B-CRS2-P3	539	70.7	45.1	15.3
	Test01-A-CRS1-P1.5	19.2	34.6	34.2	17.6
	Test02-B-CRS2-P1.5	28.9	49.1	42.7	26.1
Side 50kph MDB test	Test01-A-CRS1-P1.5	23.7	47.0	51.9	11.4
	Test01-A-CRS1-P3	83	32.9	25.5	7.1

Figure 29 shows head and chest resultant cumulative 3ms accelerations in seven FRB tests. As the chest acceleration was not known for Test 06, the data of Test 06 is not involved in Figure 29. It can be seen that all the chest resultant accelerations were worse than the better performance limit value, and the head resultant accelerations in four tests (Tests 01 to 04) were worse than the better performance limit value. The chest resultant accelerations in four tests (Tests 03, 04, 05, and 08) were even worse than the worse performance limit value, and the head resultant accelerations were all better than the worse performance limit value except in Test 03. Figures 30 and 31 show the injury assessment values normalized by IARVs for the eight 50kph FRB tests (chest acceleration for Test 06 was not involved). It can be seen from Figures 30 and 31 that the normalized HIC15/36 and chest z acceleration have more variation than head resultant and chest resultant accelerations. Chest z accelerations in Tests 07 and 08 were better than the better performance limit value (Figure 30). Chest z accelerations in Tests 03 and 05 were worse than the worse performance limit value (Figure 31).

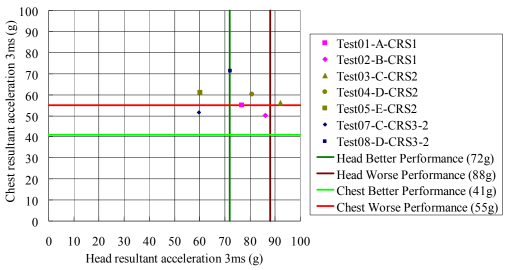


Figure 29. Head and chest resultant cumulative 3ms accelerations (50kph FRB)

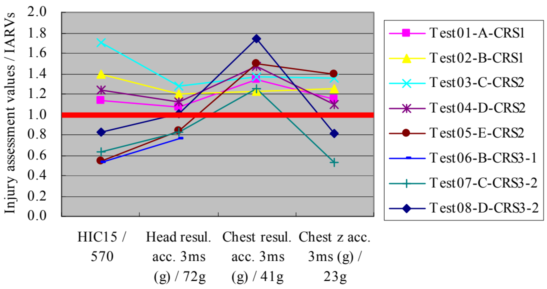


Figure 30. HIC15 normalized by 570, head and chest resultant， and chest z accelerations normalized by the better performance limit values (50kph FRB)

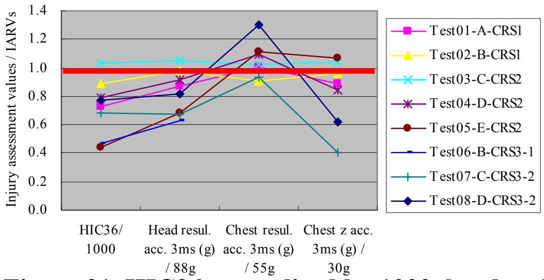
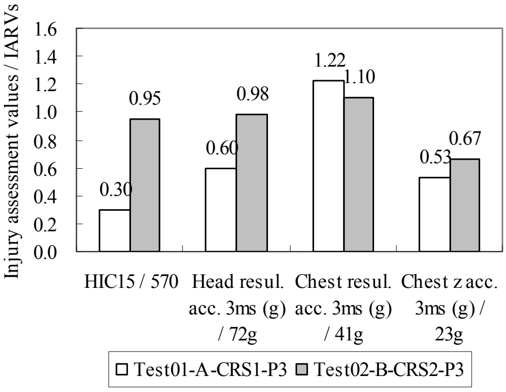


Figure 31. HIC36 normalized by 1000, head and chest resultant, and chest z accelerations normalized by the worse performance limit values (50kph FRB)

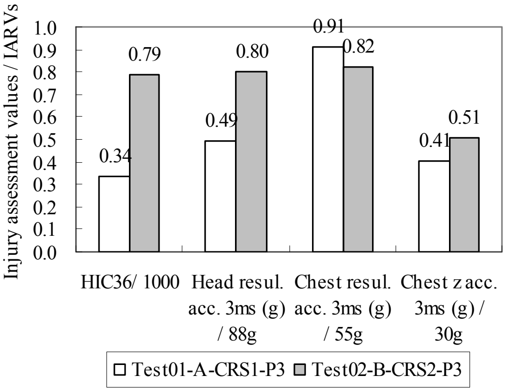
The 5-point harness type CRS 2 (Tests 03, 04, and 05) which was installed by the vehicle 3-point seatbelt, performed inferior to other CRSs in the 50kph FRB tests. Both head and chest accelerations were higher than the other CRSs and beyond the injury reference values used in Euro NCAP 64kph ODB testing. The 5-point harness type CRS 1 (Tests 01 and 02) which was installed by ISOFIX and support leg, performed better than CRS 2. The impact-shield type CRSs 3-1 and 3-2 performed well in head protection since the head accelerations in Tests 06, 07, and 08 were low compared to other tests.

Figures 32 to 35 show the injury assessment values normalised by IARVs for P3 and P1.5 in the two 64kph ODB tests. It can be found that P3 head accelerations were better than the better performance limit values for both CRSs in the two tests (Figure 32), while the P3 chest accelerations were worse than the better performance but better than the worse performance limit values for both CRSs, and the chest acceleration for CRS 2-P3 was slightly lower than that for CRS 1-P3 (Figures 32 and 33). P1.5 head and chest accelerations for CRS 1-P1.5 were all better than the better performance limit values (Figure 34). For CRS 2-P1.5, the P1.5 head z, and chest resultant and z accelerations were slightly worse than the better performance limit values but better than the worse performance limit values (Figures 34 and 35). For both head and chest accelerations, CRS 1-P1.5 performed better than CRS 2-P1.5.

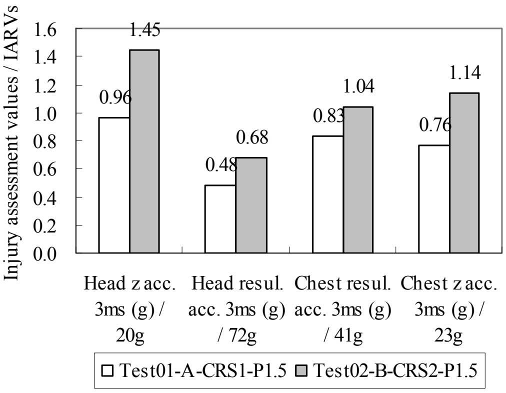
The safety performances of CRS 1-P3 and CRS 2-P3 were similar, while CRS 1-P1.5 performed better than CRS 2-P1.5. The P3 injury values in the 64kph ODB tests were generally lower than those in the 50kph FRB tests indicating the FRB tests are more severe for CRS evaluations.



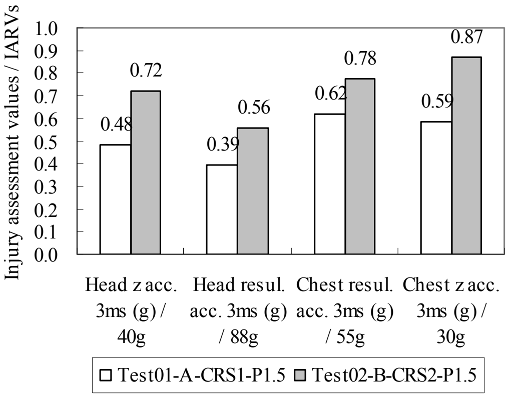
Figures 32. HIC15 normalized by 570, head and chest resultant, and chest z accelerations normalized by the better performance limit values for P3 (64kph ODB)



Figures 33. HIC36 normalized by 1000, head and chest resultant, and chest z accelerations normalized by the worse performance limit values for P3 (64kph ODB)



Figures 34. Head and chest resultant and z accelerations normalized by the better performance limit values for P1.5 (64kph ODB)



Figures 35. Head and chest resultant and z accelerations normalized by the worse performance limit values for P1.5 (64kph ODB)

According to EuroNCAP protocol, there are a total of 24 points available for dynamic tests to assess the child occupant protection in 64kph ODB and 50kph MDB tests. For the 64kph ODB Test 01, only the P3 chest resultant acceleration (ref to Table 4 50g) lost 2.571 points, and for the 50kph MDB test, no points were lost. So the total points for the dynamic tests was 21.429 points.

DISCUSSION

This paper studied child dummies kinematics and responses when restrained by CRSs in different impact tests. Different CRS installation methods: by vehicle 3-point seatbelt or ISOFIX anchorages system; Different internal restraint systems: 5-point harness type or impact-shield type; Different crash pulses produced by different cars: passenger car, compact passenger car, or SUV; All these factors influenced the child occupant safety performance metrics.

Firstly, considering different installation methods, it was known previously that the head forward excursion was generally smaller for a 5-point harness ISOFIX CRS than a universal CRS which was installed by a vehicle 3-point seatbelt [3]. Although for the tests discussed in this paper, it was difficult to determine the P3 head forward excursions from the films due to software limitations. However, from the 50kph FRB tests, it was found that the head forward excursion was even larger for the ISOFIX CRS with a support leg (Test 01 - Figure 12) than the universal CRS (Test03 – Figure 14). The forward movement of the CRS seatback contributed to the head excursion (Test 01 - Figure 12). The ISOFIX CRS with support leg used in Test 01 was much heavier and larger than other CRSs. The head forward excursion was comparable for the impact-shield CRS installed by LATCH and the vehicle 3-point seatbelt (Tests 06 and 07). Two reasons were considered why the head forward excursion was large for both the universal and the ISOFIX CRSs. One was that the crash pulses of the 50kph FRB tests were more severe than the pulses in the ECE R44 dynamic tests [3] and Euro NCAP 64kph ODB tests; The second reason was the locations of the ISOFIX lower anchorages and the location of the top tether anchorage, on the seat structure or on the vehicle body. These influenced the forward movement of the CRS, and consequently influenced the head forward excursion. For Vehicle A in Test 01, the ISOFIX lower anchorages were on the vehicle body. For Vehicle B in Tests 02 and 06, the ISOFIX lower anchorages were on the rear seat structure, while the top tether anchorage was on the vehicle body. So for both cars, the anchorages would not adversely influence the head forward excursions. Based on the head and chest accelerations in the 50kph FRB tests (Table 4), the ISOFIX CRS (Tests 01 and 02) performed better than the universal CRS (Test 03 and 04). For the impact-shield CRSs, the head acceleration for the LATACH CRS was also lower than the universal CRS.

Secondly, regarding the internal restraint systems, the impact-shield CRS (Tests 06, 07, and 08) performed better for the head acceleration than the 5-point harness CRS (Tests 01, 02, 03, and 04) in the 50kph FRB tests. The head acceleration was directly affected by the neck loads. For the 5-point harness CRS, the shoulder harness restrained the shoulder and chest, and consequently, the lower neck was restrained while the upper neck had a large axial force under the head forward and downward movement. Thus the head acceleration was high. However for the impact-shield CRS, the restraint force was applied to the chest and abdomen through the shield. Since no straps restrained the shoulder, the head restrained by the upper neck, and the lower neck restrained by the upper torso rotated downward together. Thus the upper neck axial force was controlled and the head acceleration was reduced.

Thirdly, considering different crash pulses due to different cars in the 50kph FRB tests, head and chest accelerations increased faster and peaked earlier for the compact passenger car (Test 04) than other cars because of the stiffer crash pulse in the compact car. The head acceleration for the SUV (Test 05) was much lower than the compact passenger car (Test 04). Vehicle-CRS combination is very important, but we could not assess that from the current test data in this paper and additional research is needed for that.

In the frontal impact tests, the vehicle crash pulse had much more influence on the head acceleration than the chest acceleration, while the chest acceleration was more dependent on the CRS internal restraint system. The P3 chest accelerations in the eight 50kph FRB tests and in the two 64kph ODB tests were all worse than the threshold value indicated for better performance in Euro NCAP testing. The time of the seatbelt force peaks were close to the time of the chest acceleration peaks. It could be helpful to reduce the belt forces by using a load limiter, in order to reduce the chest acceleration. A load limiter has been found to be useful in reducing both head and chest accelerations when used in the top tether for an ISOFIX CRS [4].

The head and chest accelerations of the P3 on the barrier overlap side in the 64kph ODB tests were generally lower than those in the 50kph FRB tests. Besides the influence of the vehicle crash pulses, the installation methods of the CRSs, and the performance of different types of CRSs used in the tests had also influence on the dummy responses.

In the side 50kph MDB test, the non-struck-side CRS rotated sideways to a large degree, which caused the P3 head to be exposed partly from the CRS shell. Reducing the rotation of the CRS is very important for the head containment. The gap between the CRS shell back and the vehicle seat back had a negative influence on CRS rotation. In the next tests a new designed CRS base which reduces the gap between the CRS shell back and the vehicle seat back will be used.

There were several concerns about the usability of the CRSs. The P3 torso bent forward a lot when restrained by the impact-shield CRS in the 50kph FRB tests (Tests 06, 07, and 08). The shield even fractured in the tests. As there is not a chest displacement transducer in the P-series dummies, the chest displacement was not known for the tests using this dummy. However from the previous and current research [3, 5], it was found that the chest displacement for Hybrid III 3YO and Q3 restrained by an impact-shield type CRS was usually larger than in other types of CRSs. The vehicle 3-point seatbelt had abrasion caused by the guide loops which are located on the two sides of the shield in the 50kph FRB tests. The weight of an ISOFIX CRS is generally higher than that of a universal CRS. This will make negative impact on the usability and performance.

The rear seat 3-point seatbelts used in the tests were the common seatbelt without pretensioner and load limiter. The effectiveness of the pretensioner and load limiter for the seatbelt to install CRSs will be researched through computer simulations in the next study.

CONCLUSIONS

Based on the test data from eight frontal 50kph FRB tests, two frontal 64kph ODB tests, and one side 50kph MDB test done according to CNCAP and Euro NCAP. The results are summarized as follows.

1) In front impact tests, the child dummy kinematics and responses were influenced by both the vehicle crash pulse and the safety performance of the CRS itself. The P3 injury values in the 64kph ODB tests were generally lower than those in the 50kph FRB tests indicating the FRB tests are more severe for CRS evaluations.

2) The vehicle crash pulse had much more influence on head acceleration than chest acceleration in front impact tests, while the chest acceleration was more dependent on the CRS internal restraint system.

3) In the side impact test, the head of the struck-side P1.5 was contained within the CRS shell during the entire crash event. The head accelerations for both P1.5 and P3 dummies in the side impact test were all much better than the threshold value indicated for better performance in Euro NCAP testing.

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