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RESEARCH ARTICLE

Comparative Study on the Protective Performance of Typical Child Safety Seats Based on Experiments

Donghui Hao[1,2,3]*, Jie Zhang[1], Yi Qiang[2,3], Jianying An[4] and Dechen Li[5]

[1]School of Mechanical Engineering, University of Science and Technology Beijing, Beijing, China
[2]China Academy of Machinery Science and Technology Group Co., Ltd., Beijing, China
[3]China Certification Centre For Automotive Products Co., Ltd., Beijing, China
[4]State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing, China
[5]Alwaysrise (Hangzhou) Safety Technology Co., Ltd., Hangzhou, China

ABSTRACT – With the continued rise in global vehicle ownership, the safety of child occupants has garnered increasing research attention. However, United Nations Regulation No. 129 (UN R129) currently lacks injury assessment criteria for the crotch region—specifically, the perineal area and anterior pelvic soft tissues—primarily due to the absence of dedicated sensors in existing child anthropomorphic test devices (ATDs). To address this limitation, the present study proposes a qualitative evaluation method by placing quail eggs, chicken eggs, and modeling clay in the crotch region of a 3-year-old child dummy in order to observe deformation responses under crash loading. Comparative tests were conducted on child restraint systems featuring 5-point and 6-point harness configurations under frontal/lateral impact and overturning conditions in accordance with UN R129 protocols. The results indicate that the 6-point harness system significantly reduces soft tissue compression and mitigates the risk of pelvic injury during frontal impacts while also improving control of dummy kinematics in lateral impact and overturning scenarios. Overall, the 6-point harness demonstrated superior protective performance compared to the conventional 5-point system. These findings underscore the critical need to enhance protective measures for the perineal and lower pelvic regions in child occupants. The study further advocates for the development of child ATDs equipped with high-resolution crotch-area sensors and recommends integrating computational simulations with physical testing to establish a robust quantitative framework for evaluating injuries in the crotch region.

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1. INTRODUCTION

With the development of the economy and society, people's living standards have been improving year by year, leading to an increasing number of private cars entering households. Whether for daily commutes to school or for holiday travel, cars have become the norm as a mode of transportation. The safety of occupants, especially child occupants, should be given sufficient attention. According to the Global Status Report on Road Safety 2018 [1], released by the World Health Organization (WHO), traffic accidents have become the primary killer of children, and the number of children who die from traffic accidents every year has even exceeded the impact of HIV/AIDS, tuberculosis, diarrhea, and other diseases on children's lives, with one-third of them dying during the journey. The report emphasizes that not enough attention has been paid to children's traffic safety in previous child health issues and calls for sufficient strengthening and attention to children's traffic protection. If a child occupant does not use a child safety seat that is suitable for their height or weight during travel, they will face a fatal risk. When a vehicle collides at a speed of 50 km/h, the head and chest acceleration of a 15-kg, 3-year-old child occupant can instantly reach 60–70 g [2]. This process can cause serious concussions, skull fractures, and rib fractures for child occupants. If there is a collision with the front interior of the cabin, the consequences could be even more severe. Studies indicate that such collisions often result in higher rates of severe injuries and fatalities. According to data released by the WHO, the risk of injury is reduced by 50% to 80% for children aged 0 to 4 who use child safety seats and by 52% for children aged 5 to 9 who use child safety seats.

Continuously improving the protective performance of Child Restraint Systems (CRS) remains a critical measure to safeguard child occupants during vehicle crashes. To date, a substantial body of research has systematically explored strategies to enhance the protective efficacy of CRS for child occupants and reduce injury metrics in key anatomical regions—such as the head, neck, chest, etc.—during collisions. For instance, Tanaka et al. [3] utilized Hybrid III 3YO and Q3 dummies to compare the kinematic responses and injury outcomes of child occupants using 5-point harness and impact-shield child safety seats in sled tests. Han et al. [4] conducted Q3 dummy sled tests, animal tests, and finite element simulations to assess the protective performance of impact-shield and 5-point harness systems, with a specific focus on their effectiveness in reducing chest injuries. Ahmad et al. [5] compared ISOFIX and seatbelt installation methods in

***CORRESPONDING AUTHOR | Donghui Hao** | ✉ haodh@cccap.org.cn

terms of their protective performance for child occupants based on test results from the ASEAN New Car Assessment Program (ASEAN NCAP). Zhang et al. [6] examined the influence of technical parameters of I-Size child safety seats on occupant protection in frontal collisions, using computer simulations to identify optimal values for the backrest angle, seat cushion angle, and five-point harness positioning. Additionally, several other studies [7–21] have investigated child safety seat performance through crash tests and numerical simulations.

Despite the significant progress made in enhancing the overall protective performance of CRS, existing studies have solely focused on the injury evaluation of typical body parts of child occupants as specified in standards (e.g., injury assessments for the head, neck, chest, and abdomen in accordance with UN R129 requirements)[22]. Notably, research and attention to the injury risks in the crotch area of child occupants have not been addressed to date. It is worth noting that the crotch region contains key structures critical for a child's skeletal development, such as pelvic growth plates and the femoral neck. Under collision loads, this area is susceptible to combined forces from the trunk and femur, potentially leading to two types of injuries:

i) Growth plate injury: Due to the unclosed pelvic growth plates in children, high-energy impacts may cause growth plate avulsion, directly interfering with normal skeletal growth and development or even leading to growth disorders;

ii) Soft tissue injury: During a collision, the high-speed friction of the seat belt webbing against the crotch skin may result in epidermal abrasions, subcutaneous hematomas, or deep tissue contusions.

The critical reason for this research gap lies in the technical limitations of existing anthropometric test devices (ATDs). Take the Q3 child test dummy (suitable for approximately 3-year-old child occupants) as an example—its sensor configuration does not cover the crotch region, resulting in missing or incomplete biomechanical data collection for this area, which severely restricts the development of related research. To overcome the limitations of current testing conditions, this study proposes a qualitative assessment method for crotch injury risks: by placing fragile materials (such as quail eggs, chicken eggs, or clay) at the hip position of the Q3 dummy, the injury risk to the child occupant's crotch is indirectly evaluated based on the deformation or damage degree of the materials after collision tests. This method has its limitations, as it still cannot quantitatively measure specific injury parameter values for the crotch area of child occupants. However, it can qualitatively and intuitively assess the injury risks to the crotch during collisions. While this qualitative evaluation can provide preliminary risk identification, it struggles to meet the demand for precise data in scenarios such as regulatory formulation and product optimization. It is hoped that in the near future, child dummies equipped with high-performance crotch sensors will be developed to directly obtain key biomechanical data during collisions, including crotch force, displacement, and stress distribution. This will enable the establishment of more accurate injury prediction models and ultimately achieve a technological leap from qualitative assessment to quantitative protection, comprehensively enhancing the safety of child occupants during vehicle travel.

Therefore, based on the aforementioned qualitative assessment method, this study will conduct collision and overturning performance tests on two widely used commercial child safety seats: 5-point and 6-point harness systems. During the experiments, quail eggs, chicken eggs, and clay will be positioned in the crotch area of the Q3 child dummy (representing 3-year-old occupants) as simulation materials. Injury risks to the crotch during collisions will be qualitatively evaluated by observing material damage and deformation. Additionally, protective performance differences between the two seats will be compared across different collision scenarios (e.g., frontal collision, side collision, and overturning). The results aim to provide a scientific basis for optimizing child restraint system designs, particularly in addressing unaddressed crotch protection needs.

This paper is organized as follows: Section 1 introduces the research background and outlines the research objectives, specifically focusing on evaluating the protective performance of 5-point and 6-point harness child safety seats for child occupants. Section 2 discusses the structural characteristics, analyzing and comparing the features of 5-point and 6-point harness child safety seats. Section 3 covers the methodology, outlining the test samples, conditions, dummies, test plan matrix, and evaluation criteria. Section 4 focuses on the overturning test, presenting the results for both the 5-point and 6-point harness child safety seats, followed by a comparative analysis. Section 5 addresses the lateral impact test (24 km/h), presenting the results for both types of seats, along with a comparative analysis. Section 6 presents the results of the frontal impact test (50 km/h) for the 5-point and 6-point harness child safety seats, followed by an analysis and comparison of their protective performance for child occupants. Section 7 discusses the protective performance of the 5-point and 6-point harness child safety seats based on the overturning and sled tests (frontal impact at 50 km/h and lateral impact at 24 km/h). Finally, Section 8 concludes the paper with a summary of the research findings.

2. STRUCTURAL CHARACTERISTICS

2.1 5-Point Harness Child Safety Seat

The 5-point harness child safety seat is a common type available on the market, as depicted in Figure 1. The term '5-point' refers to the locations where the harness webbing attaches to the child's safety seat. Figure 1 illustrates the positions of various points on the seat. Points 1 and 6 are located at each shoulder, while points 4 and 10 are positioned at the child's hips. Point 11 is situated between the child's legs. 2 and 7 represent the two shoulder belts, 3 and 8 indicate the two hip belts, and 5 denotes the crotch belt. 9 corresponds to the harness buckle, where all the belts are connected.

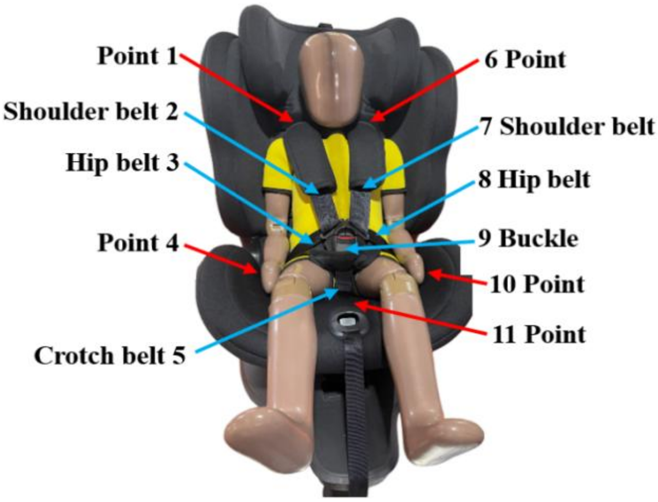


Figure 1. 5-point harness child safety seat

2.2 6-Point Harness Child Safety Seat

The 6-point harness child safety seat, as illustrated in Figure 2, is a commonly used type available on the market. The term '6-point' refers to the six locations where the harness webbing is anchored to the seat. Specifically, points 1 and 7 are located at the shoulders, points 4 and 10 at the hips, and points 6 and 13 between the legs, with a certain spacing to reduce pressure on the crotch area. 2 and 8 represent the shoulder belts. 3 and 9 indicate the hip belts. 5 and 12 denote the crotch belts. 11 is the central harness buckle where all the belts converge.

Figure 2. 6-point harness child safety seat

2.3 Comparison Between the 5-Point Harness and the 6-Point Harness

The primary difference between the 5-point and 6-point harness child safety seat lies in the configuration of the crotch belt. The 5-point harness features a single fixed point between the child occupant's legs, resulting in one crotch belt. In contrast, the 6-point harness has two fixed points positioned apart between the legs, leading to the inclusion of two separate crotch belts.

3. METHOD AND MATERIALS

3.1 Test Sample

Two types of child safety seat samples are used in the experiment: Sample A is the 5-point harness child safety seat (refer to Figure 1), and Sample B is the 6-point harness child safety seat (refer to Figure 2). Except for the 5-point harness and 6-point harness, the structures of sample A and sample B are completely identical. They are suitable for child occupants in the same height range and have the same installation method, ISOFIX + support leg, and the same webbing characteristics. The surface cover is made from the same material; the only difference is in color, which does not affect performance, etc. Refer to Table 1 for sample information (samples A and B).

In the frontal impact tests, quail eggs, chicken eggs, and clay are used as injury proxies to assess the effectiveness of both the 5-point harness and the 6-point harness child safety seats in protecting the crotch region of child occupants. These materials are placed in the child dummy's crotch position during the tests. The effectiveness of the protection is determined based on the integrity of the eggs or the deformation of the clay after the impact. If the egg remains intact or the clay shows no deformation, it indicates that the crotch protection is effective. Conversely, if the egg shatters or the clay deforms, it suggests a potential risk to the protection of the child's crotch. The quail egg, chicken egg, and clay are shown in Figure 3 (a), (b), (c), respectively. Additionally, a small piece of clay is shaped into a circular form to simulate the child’s genitals. The child dummy wears underpants equipped with a small pocket in the crotch area to hold the egg or clay during the test, as depicted in Figure 3 (d).

Table 1. Sample information

Sample	Occupant range	Installation	Restraint of child occupant	Remark
A	76-105 cm	ISOFIX + Support leg	5-point harness	Only the crotch belts are different.
B	76-105 cm	ISOFIX + Support leg	6-point harness	

Due to the current lack of sensors capable of collecting force or acceleration data in the crotch area of the child dummy, quail eggs, chicken eggs, and clay were used as provisional injury proxies to assess the risk of crotch injuries. While this method is innovative, it has inherent limitations. These materials do not provide biomechanical validation against actual injury criteria and may not accurately reflect the forces experienced by the child’s pelvic region during a collision. Furthermore, the absence of biomechanical sensors for direct force measurement in the crotch area limits the accuracy of the injury assessment. To address these limitations, future studies will refine the experimental design and incorporate appropriate sensors for directly measuring the forces in the crotch area, enabling more precise and biomechanically validated injury assessments.

(a) (b) (c) (d)

Figure 3. (a) quail egg, (b) chicken egg, (c) clay, (d) underpants for child dummy

3.2 Test Matrix

This study includes overturning tests and sled tests, which involve frontal impact tests at 50 km/h and lateral impact tests at 24 km/h. It is grounded in evaluating the actual protective capabilities of child safety seats in accordance with the requirements outlined in the UN R129 standard. UN R129 specifies the performance limits for protecting child occupants (head, neck, chest, and abdomen) under impact conditions. Furthermore, the protective performance of child safety seats on the crotch area of child occupants during frontal impacts is also considered. Quail eggs, chicken eggs, and clay are placed individually in the crotch area of the child dummy during the frontal impact tests. In summary, both the 5-point harness and the 6-point harness child safety seats will undergo one overturning test in four directions and one lateral impact test. Additionally, for the frontal impact tests, each of the 5-point harness and the 6-point harness child safety seats will undergo three tests. In each test, a quail egg, a chicken egg, and clay will be placed individually in the crotch area of child dummies. The test matrix is referenced in Table 2.

Table 2. Test matrix

Items	Sample	Dummy	Conditions	Remarks
Overturning	A: 5-point B: 6-point	Q3	At a speed of 2-5°/s	Rotated around the axis in the horizontal and longitudinal planes
Lateral impact	A: 5-point B: 6-point	Q3	24 km/h	/
Frontal impact	A: 5-point B: 6-point	Q3	50 km/h	Crotch: Quail egg
	A: 5-point B: 6-point	Q3	50 km/h	Crotch: Chicken egg
	A: 5-point B: 6-point	Q3	50 km/h	Crotch: Clay

3.3 Experimental Evaluation Method

3.3.1 Overturning

At no point during the whole test shall the dummy be fully ejected from the child safety seat, and in addition, when the test bench is in the upside-down position, the dummy's head shall not move more than 300 mm from its original position in a vertical direction relative to the test bench once the applied load has been removed.

3.3.2 Impact test

During the collision process, except for the components and systems that limit the load, any component of the CRS used to restrain the occupant should not be completely or partially broken. The child occupant's protective performance of the CRS is usually evaluated based on the displacement of the test dummy’s body and the injury values of different parts of the test dummy’s body. In the experiment, different dummies (human substitutes) may be used, but different dummies may have different measurement parameter capability ranges. According to UN R129, the injury limits for child occupants of different ages in frontal and rear collisions are shown in Table 3, and the injury limits for child occupants in lateral collisions are shown in Table 4.

Table 3. Injury limits requirements of UN R129 (frontal and rear collisions)

Criterion	Abbreviation	Unit	Q0	Q1	Q1.5	Q3	Q6	Q10
Head performance criterion (only in case of contact during in-vehicle testing)	HIC_{15}		600	600	600	800	800	800
Head acceleration 3 ms	A_{H3ms}	g	75	75	75	80	80	80
Upper neck tension Force	F_z	N	For monitoring purpose only					
Upper neck flexion moment	M_y	Nm						
Chest acceleration 3 ms	A_{C3ms}	g	55	55	55	55	55	55
Chest deflection	D	mm		NA		For monitoring purpose only		
Abdominal pressure	P	bar	NA	NA	1.2	1.0	1.0	1.2

Table 4. Injury limits requirements of UN R129 (Lateral Impact)

Criterion	Abbreviation	Unit	Q0	Q1	Q1.5	Q3	Q6	Q10
Head performance criterion (only in case of contact during in-vehicle testing)	HIC_{15}		600	600	600	800	800	For monitoring purpose only
Head acceleration 3 ms	A_{H3ms}	g	75	75	75	80	80	For monitoring purpose only
Upper neck tension Force	F_Z	N	For monitoring purpose only					
Upper neck flexion moment	M_y	Nm						

3.4 Test Dummy

In the experiment, an anthropomorphic substitute equivalent to a 3-year-old child as specified in standard UN R129, namely the Q3 child dummy, was used. Please refer to Figure 4 for the Q3 child dummy.

Figure 4. Q3 child dummy

3.5 Test Environment and Condition

The test environment and the test equipment meet the requirements of the UN R129 testing conditions. In this test, a 3-year-old child dummy Q3 was used, and the dummy was calibrated according to standard requirements. The calibration cycle was set to 1 out of 20 collisions, and the joint friction of the dummy was adjusted before each test. The joint bolts of the shoulders, elbows, knees, etc., were adjusted to have a stable friction of 1g to 2g. The experimental environment temperature should be maintained at 20 ± 2 °C, and the relative humidity should be 40% ± 30%.

4. RESULTS AND DISCUSSION

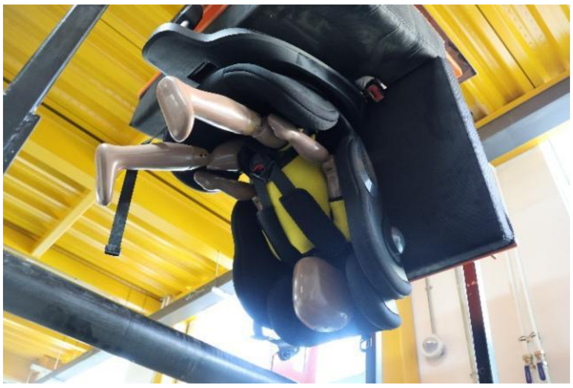
4.1 Test Results

Overturning tests were conducted using the Q3 child dummy seated in both the 5-point and 6-point harness child safety seats. Throughout the entire test, the Q3 dummy must not be fully ejected from the restraint system. Additionally, when the test bench reaches the upside-down position, the vertical displacement of the dummy's head, relative to the test bench, must not exceed 300 mm once the applied load has been removed. The results of the overturning tests for both harness types are presented in Table 5.

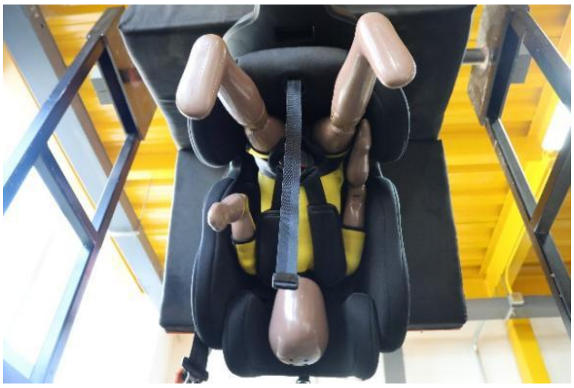
Table 5. Overturning test results (5-point / 6-point harness child safety seat)

With harness	Limits	Displacement (mm)				Remarks
		Rotation clockwise	Rotation counter clockwise	Rotation forward facing	Rotation rearward facing	
5-point	No fully ejected; Head vertical displacement ≤300	79	78	77	69	Pass
6-point		73	70	67	65	Pass

The test pictures of the 5-point harness child safety seat are shown in Figure 5. The test pictures of the 6-point harness child safety seat are shown in Figure 6.


(a) clockwise


(b) counter clockwise


(c) forward facing

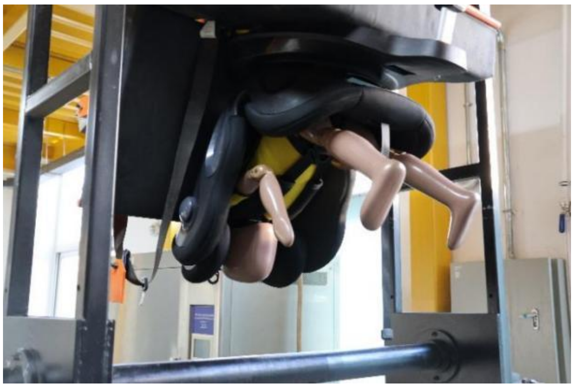
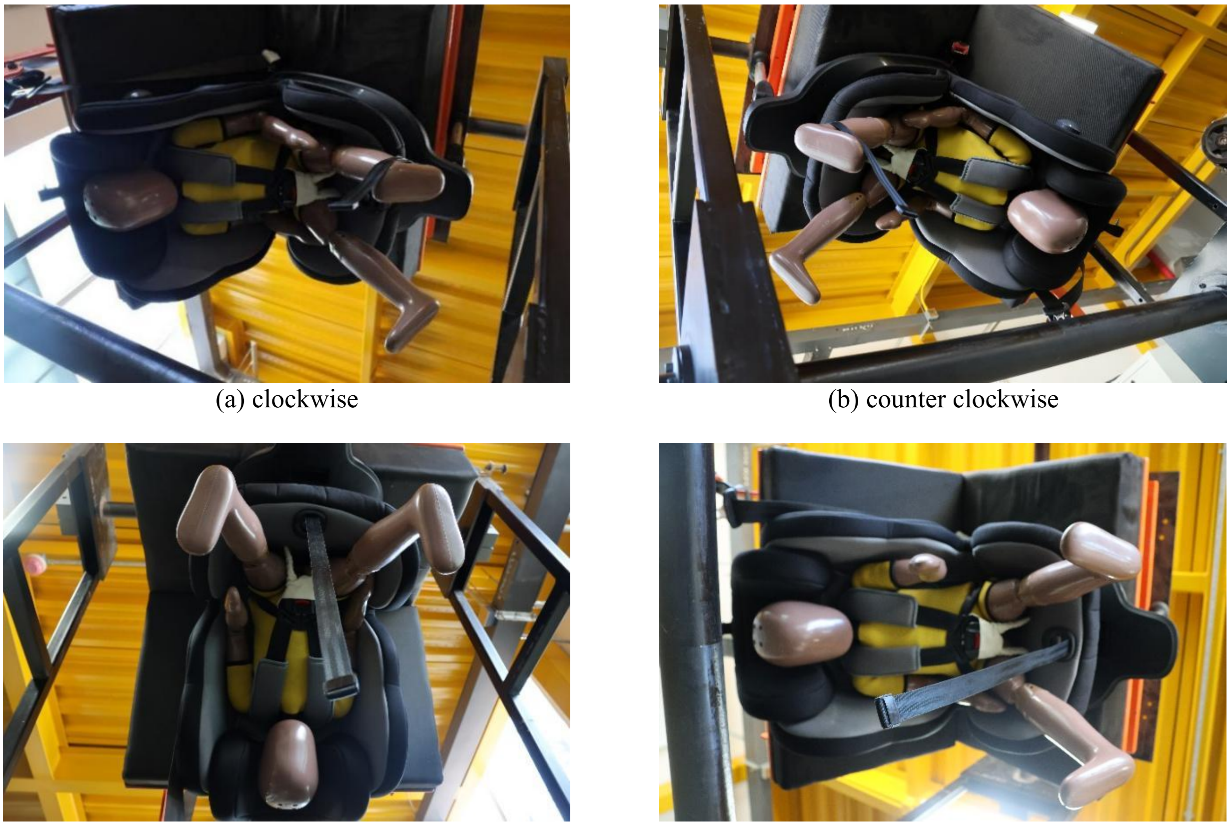

(d) rearward facing

Figure 5. Overturning 5-point harness child safety seat



(a) clockwise (b) counter clockwise

(c) forward facing (d) rearward facing

Figure 6. Overturning 6-point harness child safety seat

4.2 Test Analysis

As shown in Table 5, the vertical displacement of the dummy's head was consistently lower in the 6-point harness child safety seat across all four overturning directions. Specifically, during clockwise rotation, the displacement was 73 mm for the 6-point harness seat compared to 79 mm for the 5-point harness. For counterclockwise rotation, the values were 70 mm and 78 mm, respectively. In the forward-facing test, the 6-point harness recorded 67 mm versus 77 mm for the 5-point harness, and in the rear-facing test, the displacements were 65 mm and 69 mm, respectively. Based on the test results, it can be concluded that both the 5-point and 6-point harness child safety seats comply with the overturning protection performance requirements outlined in UN R129. In all four rotation directions, the Q3 child dummies were not fully ejected from the child restraint systems (CRS), and the vertical displacement of the dummy's head remained within the 300 mm limit relative to its original position. In terms of protective performance, the 6-point harness child safety seat demonstrates superiority over the 5-point harness seat. This advantage is primarily due to its two crotch belts, which independently secure the child occupant's thighs, thereby minimizing lateral movement of the buttocks. Additionally, the design helps prevent direct compression and friction in the crotch area, offering enhanced comfort and protection.

5. LATERAL IMPACT (24 KM/H)

5.1 Test Results

Lateral impact tests (24 km/h) are conducted with the Q3 child dummy seated in both the 5-point harness child safety seat and the 6-point harness child safety seat. During the loading phase of lateral impact testing, up to 80 ms, head containment is assessed by the following:

i) The dummy's head should be inside the door reference plane.

ii) There must be no contact between the head and the door panel.

iii) Head injury assessment criteria include HIC15 ≤ 800 and A3ms (g) ≤ 80, while neck force and neck bending moment shall be monitored.

Lateral impact test results (5-point harness / 6-point harness child safety seat) are shown in Table 6.

Table 6. Lateral impact test results (5-point harness / 6-point harness child safety seat)

Body		Limits	5-point harness	6-point harness
Head	Dummy's head inside door reference plane	Yes	Yes	Yes
	Contact with door panel	No	No	No
	HIC15	≤ 800	496	494
	A3ms (g)	≤ 80	58	56
Neck	Fz (kN)	monitor	1.98	1.96
	My (Nm)	monitor	20.1	19.4

The lateral impact test pictures of the 5-point harness child safety seat are shown in Figure 7 (a), (b) and (c). The lateral impact test pictures of the 6-point harness child safety seat can be found in Figure 7 (d), (e) and (f).

(a) (b) (c)

Q3/5-point harness child safety seat

(d) (e) (f)

Q3/6-point harness child safety seat

Figure 7. Lateral impact test pictures

5.2 Test Analysis

As shown in Table 6, the lateral impact test results indicate that the Q3 child dummy's head remained within the door reference plane and did not contact the door panel, regardless of whether the dummy was seated in the 5-point or 6-point harness child safety seat. For the 5-point harness seat, the head injury criteria recorded were HIC15 = 496 and A3ms = 58 g. For the 6-point harness seat, the values were slightly lower, with HIC15 = 494 and A3ms = 56 g. Regarding neck injury metrics, the 5-point harness seat resulted in a neck axial force (Fz) of 1.98 kN and a neck bending moment (My) of 20.1 Nm. In comparison, the 6-point harness seat showed slightly reduced values, with Fz = 1.96 kN and My = 19.4 Nm. Based on the test results, it can be concluded that both the 5-point harness child safety seat and the 6-point harness child safety seat meet the lateral protection performance requirements of UN R129. When comparing protective performance, there is not much difference in the lateral impact protection between the 5-point harness child safety seat and the 6-point harness child safety seat.

6. RESULTS AND DISCUSSION

6.1 Test Results

Frontal impact tests at 50 km/h were conducted using the Q3 child dummy seated in both the 5-point and 6-point harness child safety seats. To assess crotch protection, quail eggs, chicken eggs, and clay were placed in the crotch area of the dummy. These materials help evaluate the level of protection offered by each seat design for the child occupant's crotch region. According to UN R129 requirements, the head excursion of the dummy during impact must remain within defined reference planes: the X-direction (forward) excursion must be less than 500 mm, and the Z-direction (vertical) excursion must be less than 800 mm. Injury assessment criteria include HIC15 ≤ 800 and A3ms ≤ 80 g for the head; neck axial force (Fz) and neck bending moment (M) for the neck; A3ms ≤ 55 g for the chest; and abdominal pressure (P, L/R)

< 1.0 bar. For the crotch, protection is assessed based on whether the eggs remain intact and whether the clay shows signs of deformation. The frontal impact test results for both child safety seat types are presented in Table 7.

Table 7. Frontal impact test results (5-point harness child safety seat/6-point harness child safety seat)

Body		Limits	Crotch placement					
			Quail egg		Chicken egg		Clay	
			5-point harness	6-point harness	5-point harness	6-point harness	5-point harness	6-point harness
Head	X (mm)	< 500	410	412	418	416	417	414
	Z (mm)	< 800	667	664	669	668	662	664
	HIC15	≤ 800	538	541	545	543	540	546
	A3ms (g)	≤ 80	66	68	65	64	70	69
Neck	Fz (kN)	monitor	2.6	2.4	2.8	2.7	2.7	2.6
	M (Nm)	monitor	24.7	24.5	23.6	23.9	24.8	24.6
Chest	A3m (g)	<55	49.7	49.8	50.6	50.4	49.9	51.3
Abdomen	P (bar) L/R	< 1.0	0.6/0.8	0.6/0.7	0.5/0.8	0.5/0.8	0.5/0.7	0.6/0.5
Crotch	Completeness	monitor	Cracked	No cracked	Cracked	No cracked	Deformed	No deformed

Both the 5-point and 6-point harness child safety seats underwent three frontal impact tests, with a quail egg, a chicken egg, and clay, respectively, placed in the crotch position of the Q3 child dummy for each test. The procedures for the three tests were consistent. To illustrate the testing process, only the frontal impact test photos involving the quail egg are presented. Refer to Figure 8 (a), (b) and (c) for the 5-point harness child safety seat and Figure 8 (d), (e) and (f) for the 6-point harness child safety seat.


(a)

(b)

(c)

Q3/5-point harness child safety seat/quail egg


(d)

(e)

(f)

Q3/6-point harness child safety seat/quail egg

Figure 8. Frontal impact test

Figure 9 (a) illustrate the condition of the quail egg, chicken egg, and clay before and after the frontal impact tests for the 5-point harness child safety seat. Prior to the impact, all three items remained intact. However, as shown in Figure 9 (d) and (e), both the quail egg and the chicken egg sustained cracks after the test. Additionally, Figure 9 (f) reveals visible deformation of the clay.

(a) quail egg (b) chicken egg (c) clay

Before impact/5-point harness

(d) quail egg (e) chicken egg (f) clay

After impact/5-point harness

Figure 9. Frontal impact tests for the 5-point harness child safety seat

Figure 10 illustrates the condition of the quail egg, chicken egg, and clay before and after the frontal impact tests for the 6-point harness child safety seat. All items were intact prior to the impact. As shown in Figure 10 (d) and (e), both the quail egg and the chicken egg remained undamaged after the tests. Figure 10 (f) further confirms that the clay also retained its original shape, indicating no visible deformation.

(a) quail egg (b) chicken egg (c) clay

before impact/6-point harness

(d) quail egg (e) chicken egg (f) clay

After impact/6-point harness

Figure 10. Condition before and after the frontal impact tests for the 6-point harness child safety seat

6.2 Test Analysis

6.2.1 5-point harness child safety seat

Table 7 presents the results of the frontal impact tests. The 5-point harness child safety seat meets the UN R129 requirements for head, neck, chest, and abdomen protection across all three test conditions (quail egg, chicken egg, and clay). During the tests, the Q3 dummy's shoulders and hips were effectively restrained by the corresponding belts, and the crotch area was secured by the single crotch belt. The forward and vertical head excursions remained within the standard limits, indicating that the dummy avoided contact with any interior surfaces of the cabin. The 5-point harness effectively distributed collision forces across the structurally stronger regions of the child's body, such as the hips and shoulders, thereby minimizing stress concentration. This configuration also helps prevent submarining. In accordance with UN R129, the 5-point harness child safety seat demonstrates satisfactory protective performance for child occupants. However, it is evident that the child's crotch area faces a significant risk of injury. In the frontal impact tests, the quail egg and chicken egg placed at the crotch position of the Q3 child dummy were both cracked, and the clay was notably deformed. This outcome can be attributed to the design of the crotch belt in the 5-point harness system. The single crotch belt is positioned directly over the pelvic region, and during frontal impacts, it can exert concentrated pressure and cause friction on this sensitive area. Such force may result in serious injuries to the pelvic organs, potentially affecting future fertility and, in severe cases, posing a life-threatening risk to child occupants.

6.2.2 6-point harness child safety seat

From Table 7, it can be observed that the 6-point harness child safety seat also complies with the UN R129 requirements for protecting the head, neck, chest, and abdomen of child occupants in frontal impact tests. The Q3 child dummy was effectively restrained by the 6-point harness system: the shoulder belts provided secure restraint at the shoulders, the hip belts at the hips, and the dual crotch belts offered targeted restraint at the thigh roots. The forward (X-direction) and vertical (Z-direction) excursions of the dummy's head remained within the prescribed limits, indicating that the child occupant would avoid contact with surrounding cabin structures. Additionally, Stress concentration is mitigated as the inertial forces generated during the collision are distributed through the 6-point harness belts to structurally stronger areas of the child occupant's body, such as the hips and shoulders, as well as to the frame of the child safety seat. Importantly, the 6-point harness effectively mitigated the risk of submarining─forward sliding of the body under the belt─thereby offering enhanced protective performance in line with UN R129 standards. The test results indicate that during the frontal impact tests, both the quail egg and the chicken egg placed at the crotch position of the Q3 child dummy remained intact, and the clay exhibited no signs of deformation. This favorable outcome can be attributed to the design of the crotch belts in the 6-point harness. Specifically, the crotch belts are spaced apart to avoid direct contact and friction with the sensitive crotch area of child occupants during frontal impacts, thereby providing enhanced protection.

6.3 Overturning

In terms of overturning tests, both the 5-point and 6-point harness child safety seats meet the overturning protection performance requirements outlined in UN R129. In all test conditions─whether clockwise, counterclockwise, forward, or backward rotation─the Q3 child dummy remained securely restrained within the device. Moreover, when the test bench was positioned upside-down, the dummy's head displacement remained within the 300 mm limit, in accordance with the standard. However, the structural characteristics of the 6-point harness offer superior restraint. The dual crotch belts, each securing the child's thigh roots individually, provide more effective restraint during the overturning process. This design minimizes the lateral movement of the child's buttocks and ensures that the pelvic area is protected from direct compression and friction exerted by the crotch belts, thereby enhancing the overall safety and protection of child occupants during the overturning event.

6.4 Lateral Impact (24 km/h)

In the lateral impact test conducted at 24 km/h, both the 5-point and 6-point harness child safety seats comply with the protective performance criteria for head and neck protection as specified in UN Regulation No. 129. While the overall protective performance of the two restraint systems is comparable, analysis of the test data suggests that the 6-point harness provides a slight advantage over the 5-point harness in enhancing child occupant protection under lateral impact conditions.

6.5 Frontal Impact (50 km/h)

Both the 5-point and 6-point harness child safety seats demonstrate effective restraint of child occupants during frontal impacts at 50 km/h. The forward and vertical displacements of the Q3 child dummy remain within the limits prescribed by UN Regulation No. 129. Furthermore, the protective performance indicators for the head, neck, chest, and abdomen are all within the standard thresholds. Both harness systems effectively maintain proper occupant positioning, making them suitable even for active children. During a collision, the harnesses distribute inertial forces across the child's shoulders, hips, and thighs, as well as into the structure of the child safety seat. This even distribution reduces stress concentration, thereby enhancing overall safety performance.

Although it is not feasible to directly quantify the pressure exerted by the crotch belt of the 5-point harness on the genital region of child occupants, nor to calculate the precise frictional forces involved, meaningful conclusions can be drawn from the observed damage to test materials during frontal impact tests. The cracking of the quail egg and chicken egg, as well as the deformation of clay placed in the crotch area of the Q3 dummy, indicate significant localized stress. These results suggest that the crotch belt of the 5-point harness may pose a substantial risk of injury to the pelvic region of child occupants. Such injuries could have serious implications, potentially affecting future reproductive health or, in extreme cases, resulting in life-threatening trauma.

In contrast, the 6-point harness child safety seat demonstrates a clear advantage in mitigating this risk due to its structural configuration. The design features two crotch belts anchored at separate fixed points, spaced apart to avoid direct alignment with the child occupant's genital area. This arrangement effectively reduces the likelihood of compression and friction during frontal impacts, thereby offering enhanced protection to the sensitive pelvic region.

7. CONCLUSION

This paper presents a comprehensive test plan based on UN Regulation No. 129 (UN R129) to evaluate and compare the protective performance of 5-point and 6-point harness child safety seats for 3-year-old children under overturning, lateral impact and frontal impact conditions. The experimental results lead to the following conclusions:

- Overturning protection: The 6-point harness child safety seat outperforms the 5-point harness in protective performance, as its two crotch belts individually restrain the child's thigh roots, reducing lateral movement and preventing direct compression or friction in the crotch area. In terms of dummy head displacement, whether during clockwise, counterclockwise, forward, or backward overturning, the child dummy in the 6-point harness safety seat shows less displacement than in the 5-point harness safety seat. For specific numerical values, please refer to Table 5.
- Lateral impact (24 km/h): The 6-point harness child safety seat demonstrates superior protective performance compared to the 5-point harness configuration. As indicated in Table 6, the injury metrics for both the head and neck are consistently lower for the Q3 child dummy seated in the 6-point harness seat. These results suggest that the 6-point harness provides more effective restraint and impact energy distribution during lateral collisions.
- Frontal impact (50 km/h): Compared to the 5-point harness child safety seat, the results presented in Table 7 indicate that the 6-point harness offers comparable levels of protection for the head, neck, chest, and abdomen while providing superior protection for the crotch and pelvic regions. This enhanced protection is attributed to the structural design of the 6-point harness, which incorporates two crotch belts anchored at distinct points, spaced apart to minimize compression and friction on the child's sensitive pelvic area during a collision. The experimental evidence—specifically, the cracking of quail and chicken eggs and the severe deformation of clay when tested with the 5-point harness—demonstrates that the single-point crotch webbing in the 5-point system presents a substantial risk of injury to the crotch organs and pelvis of child occupants.

In summary, across various experimental conditions, both the 5-point and 6-point harness child safety seats demonstrate adequate protection for the head, neck, chest, and abdomen in compliance with UN Regulation No. 129. However, notable differences arise in the level of crotch and pelvic protection. The single-point crotch webbing of the 5-point harness poses a considerable risk of injury to the child's sensitive pelvic region during frontal impacts. This finding highlights a critical area for improvement in restraint system design and underscores the need for further investigation into the long-term implications of such injuries.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORS CONTRIBUTION

Donghui Hao: Conceptualization, Methodology, Literature Review, Analysis, Writing – Original Draft.

Jie Zhang: Conceptualization, Methodology, Supervision, Writing – Review & Editing.

Yi Qiang: Conceptualization, Methodology, Supervision, Writing – Review & Editing.

Jianying An: Investigation, Data Curation – Conducted the experiments and collected the data.

Dechen Li: Methodology, Test Design, Investigation, Data Analysis.

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