

The Australian Child Restraint Evaluation Program: An Update on Dynamic Assessment Protocols and Observed Dynamic Performance of Child Restraint Systems

Julie Brown

NeuRA Injury Prevention Research Centre and University of NSW
Australia

Basuki Suratno

Dan Leavy
Transport for NSW
Australia

Paul Kelly

Michael Griffiths
Road Safety Solutions
Australia

Peter Aquilina

Roads and Maritime Services, Crashlab
Australia

Michael Paine

Vehicle Design & Research
Australia

Jack Haley

NRMA Motoring and Services
Australia

Blake Harris

RACV
Australia

Paper Number 15-0376

ABSTRACT

The purpose of the Australian Child Restraint Evaluation Program (CREP) is to provide consumers with independent safety information; and to apply commercial and public consumer pressure on manufacturers to deliver child restraint systems (CRS) that perform well beyond the requirements of the Australian Standard. This paper describes the evolution of the dynamic assessment protocols and presents a summary of areas where improvement in dynamic performance has occurred. Areas of dynamic performance where there is still room for improvement, are also reviewed.

The dynamic assessment protocol has evolved from a system that separately scored the performance of CRS in frontal, 90 degrees and 66 degrees simulated impacts to a system that provides a single overall score for front and side impact tests to determine CRS ratings. The current protocols also nominate a number of 'Critical' 'Performance Aspect' (PAs) and a CRS is limited to one star if a score of '0' is achieved for any critical PA. There have also been significant changes to the dynamic test and assessment methods over the years to ensure assessment methods are as objective as possible, and some variation in the types of performance features assessed. For rearward facing infant restraints, CREP currently assesses the ability of the CRS to retain the head and torso in front and side impacts, control upward and rotational displacement of the CRS in rebound and distribute the load over the back of the dummy, in frontal testing, , manage dummy head and torso energy in frontal testing and manage dummy head energy in side impact. Similar assessments of dummy and head retention and energy management are used in the rating of forward facing child restraints. These assessments also include head and knee excursion. For booster seats, the ability of the booster to provide and maintain good sash belt geometry, and to prevent submarining in frontal

impacts. Assessments of head retention and energy management in side impact and dummy retention both in near and off-side impacts are also included for booster seats. There have been substantial improvements in the side impact protection features of rearward facing and forward facing child restraints observed in the program, and increasingly better performance of booster seats in maintaining good seat belt geometry in frontal impact. However, there is a need for more attention to head energy management in side impact, particularly among rearward facing restraints. Among rearward facing restraints, there are also concerns about poor performance of most restraints to adequately distribute crash forces through the back of the torso in frontal impact. Among forward facing restraints, there are concerns over head containment during rebound in frontal impact.

While there have been significant improvements to the test and assessment methods used in CREP there is a possibility that some aspects of good performance are being overstated and aspects of poor performance understated due to limitations in the assessment and rating procedures. Areas for possible future refinements of the protocols are also discussed.

INTRODUCTION

A child restraint evaluation program (CREP) has been operating in Australia since 1994. The concept of the program has been described previously (Kelly et al, 1996). According to Kelly et al (1996) the program was introduced following laboratory crash test observations of substantial variations in the performance of child restraint systems coming onto the Australian market in 1993. All child restraint systems sold in Australia since 1978 have had to comply with Australia/New Zealand Standard 1754 (AS/NZS 1754 had). The Australian Standard sets a minimum level of required performance and the relatively small number of restraints on the Australian market prior to 1993 generally exceeded this level of performance in the laboratory and in the field. The observation that some new restraints from new manufacturers that were coming on the market appeared to be just meeting the minimum requirements of the Standard raised concerns that these restraints may not provide the same level of protection to children in the real world (Kelly et al, 1996). The very first iteration of the program (CREP-Stage 1) included additional tests and performance criteria to those prescribed by the Standard to establish any differences in performance beyond the minimum requirements of the Standard of restraints being sold in Australia at that time , and to bring these differences to the attention of consumers.

The results of Stage 1 were published in a national subscription consumer magazine and wider consumer access was facilitated through a publically available brochure. According to Kelly et al (1996) there was clear consumer interest in the program. It also became clear that the published information was being used by consumers as a tool in making purchasing decisions with manufacturers reporting increases in sales of restraints that ranked well, and decreases in sales of those that were rated poorly. This established the value of the program as a mechanism to apply commercial and public consumer pressure on manufacturers to deliver child restraint systems (CRS) that performed well beyond the requirements of the Australian Standard.

Two further releases of CREP results occurred in 1996 (Stage 2) and 2000 (Stage 3). These used the same general test methods, approach to assessing performance and publication strategies used in Stage 1.

In 2004 the program underwent a major review that resulted in a revised dynamic test protocol and a new approach to the overall assessment of the restraints using an objective point based method (Brown et al, 2007). Results of assessments using these new protocols were released as CREP Stage 4a & CREP Stage 4b. The assessment method was further enhanced in 2009, and the results from Stages 4A to 4D were rescored to the enhanced method and released in 2010, together with the results for CREP 4E.

Following the introduction of substantive changes to the Australian Standard in 2010 the test protocols were again reviewed in 2012 to ensure CREP stayed true to its original aim of assessing the performance of restraints sold in Australia beyond the minimum requirements of the Australian Standard. This resulted in more significant changes to the test method and inclusion of some additional performance assessments. The resulting test procedures and assessment protocols were adopted and have been used in the CREP 5 ratings. The CREP 5 rating procedures remain current with some slight modifications to allow for the assessment of ISOFIX compatible restraints.

This paper describes the evolution of the dynamic assessment protocols and presents a summary of the areas where improvement in dynamic performance has occurred. Areas of dynamic performance where there is still room for improvement are also reviewed.

EVOLUTION OF THE DYNAMIC ASSESMENT PROTOCOL

Throughout the first three releases of CREP results (CREP1-3) the assesment procedure remained relatively stable, however significnat changes were introduced in CREP 4 and CREP 5. These are summarised below.

Test Methods

While the intention of CREP since its inception has been to assess the performance of restraint systems beyond the minimum requirements of the Australian Standard, the test methods have been heavily based on the test methods included in the Standard. The test orientations and test pulses used in each iteration of the program are summarised in Table 1.

Table1.
Evolution of crash tests included in CREP assessment procedures

Sled Test	CREP Stage 1-2 (1994-1996)	CREP Stage 2 (1996-1999)	CREP Stage 3 (2000-2004)	CREP Stage 4 (2005-2012)	CREP Stage 5 (2012-present)
Frontal 48km/h 24g	RF, FF, Boosters	RF, FF, Boosters	RF, FF, HBB	-	-
Frontal 56km/h 34g	RF, FF, Boosters	RF, FF, Boosters	RF, FF	RF, FF, Boosters	RF, FF, Boosters
NS Side 90° +	RF, FF, Boosters	RF, FF, Boosters	RF, FF, HBB	RF, FF, Boosters	RF, FF, Boosters
NS Side 45° +	RF, FF, Boosters	RF, FF, Boosters	RF, FF, HBB	-	-
NS Side 66 ° +	-	-	-	RF, FF, Boosters	RF, FF
FS Side 90 ° +	-	-	-	-	Boosters
Rear Impact ⁺	RF, FF	RF, FF	RF, FF	-	-
Inverted ⁺⁺	RF	RF	RF	-	-

*RF – Rearward facing infant restraint; FF – Forward facing child seat; LBB – Low back/backless booster; HBB – High back booster; Booster – any booster seat; NS – Near side; FS – Far side.

+ Impact pulse is 32km/h 14g and static side door structure incorporated in test set up; ++ Impact pulse 16km/h 8g

Initially (Stages 1-3) CREP included two frontal impact tests; one that equaled the minimum deceleration and velocity change requirements of the Australian Standard (48km/h, 24g), and one that attempted to more closely match the assessment of adult restraint systems in the Australian New Car Assessment Program (Kelly et al, 1996). The more severe pulse used a velocity change of 56km/h and a deceleration that was as near as possible to the maximum acceleration allowed by the Australian Standard test method (34g). However in the review of the protocols prior to CREP 4, the lower severity test was removed from the protocol as this test was not producing any worthwhile information for making comparisons of performance beyond that required by the Standard.

The side impact tests included in all iterations of CREP have used the same pulse requirements as that included in the Australian Standard. The Australian Standard has required a 90 degree side impact test since 1975. However, the assessment of performance in side impact in the Standard was originally related to the restraint's ability to retain the dummy and maintain structural integrity in this orientation. To allow restraint performance to be assessed beyond this, a side door structure was added to the test set up in CREP Stage 1 and as described below, this continues to CREP 5 with some modification to the structure. The additional 45 degree side impact test was included in CREP Stage 1 in acknowledgement of field data that indicated that most side impacts included some forward component of force. In the review conducted prior to CREP 4 it was felt that there was also no worthwhile comparable information being collected from the 45° tests, and it was unclear what proportion of real world impacts this orientation was actually simulating. To maintain the intention of being

able to assess performance under oblique loading but with some justification for the orientation being used, a decision was made to move to a 66° impact as that more closely resembled the US NCAP side impact conditions at that time.

Up until CREP Stage 5, all side impact testing simulated near side impacts. In the early stages of CREP 1-4, many high back boosters demonstrated inadequacies in the retention of test dummies during rebound in these near side impacts. To address this and allow the performance of different booster seats on the market to be compared, a far side impact was included for booster seats in CREP 5.

Rear and inverted tests included in CREP Stages 1-3 were basically mimicking the tests carried out as part of compliance testing for the Standard and were not providing any information on performance beyond that required by the Standard. These tests were discontinued after CREP Stage 3.

As shown in Table 1, there has been some variation in the restraint types subjected to different tests throughout the evolution of the program. As described by Brown et al (2007), all restraints were subjected to all frontal and side impact tests in the first Stage of CREP (Stage 1). The performance of most boosters on the market in Australia at that time (early 90's) was quite poor in that first series of tests. Based on this poor performance, subsequent early CREP series treated boosters differently. High back boosters were exempted from the higher severity frontal tests due to this poor performance and test house concerns regarding the robustness of the test TNO P10 dummy in CREP Stages 2 & 3. However trials conducted prior to CREP Stage 4 alleviated these concerns and these restraints were again subjected to the higher severity frontal impact in later stages. Booster cushions (i.e. backless boosters) were excluded from CREP Stages 2 and 3 due to their inherent inability to provide any measurable protection in side impact. This was reversed in the lead-up to CREP Stage 4, as changes made to the Australian Standard prior to the commencement of CREP 4 basically removed booster cushions or backless boosters from the Australian market. As described below, the change to the Australian Standard that impacted booster cushions/backless boosters was the adoption by Standards Australia of the CREP side impact test method and assessment procedure. Therefore no backless boosters have been included in any CREP series since Stage 1.

Booster seats were never included in the rear impact or inverted tests, and forward facing restraints were always excluded from the inverted tests.

Test rig

The test equipment used throughout all stages of CREP is the same as that used in Standards testing of child restraints in Australia. This involves a test bench in compliance with the Australian standard mounted on a rebound sled. For side impact tests, a side door structure is also mounted to the sled. There has been some evolution of the side door structure over the course of the program and this is described below.

As described by Kelly et al (1996) in the original CREP (Stage 1) the side door structure attempted to replicate a simplified rear door of a large sedan in size and shape, and included an inner door skin and 'window'. The structure was fabricated from square wall tubing, the inner skin from thin sheet metal and the 'window' from 6mm Polycarbonate sheeting. The inner skin was replaced after each test. A side door structure, comprising a metal frame and polycarbonate panels, was added to the Australian Standard test procedure in 2004. The addition of this structure, together with a requirement that all restraints prevent contact between the test dummy's head and the side door meant that by CREP Stage 4 many restraints on the Australian market were able to contain the head to some extent. To this point, head accelerations and Head Injury Criteria (HIC) were being recorded in the CREP tests but not being used in scoring. Even allowing for the unknown biofidelic nature of the dummy's head, the generally very high HICs being recorded indicated a distinct lack of energy attenuating materials in CRS side structures. This led to discussion about the possibility of including some assessment of the head energy management in side impact. However, the non-uniform nature of the side door structure prevented this from being achieved. Research programs that had attempted to alter the energy absorption properties of restraint side wings were not able to measure significant differences in dummy head acceleration and HIC (Bilston et al, 2005), because altering the side wings resulted in differences in head or restraint impact location on the door. As the stiffness of the original door varied with location, any variations due to modification of the side wings were masked by changes in where the door was struck. To counter this, a new door structure with uniform stiffness was introduced in CREP Stage 5.

Dummies

The dummies used in CREP also conform to the requirements of the Australian Standard and largely belong to the TNO P series family of dummies. However, there have been changes to the types of dummies used to test different restraint types, and to how some dummies have been used over the evolution of the program. Table 2 summarises the test dummies used by restraint type and impact condition across the history of CREP.

Table2.
Test dummies used in CREP assessment procedures

Restraint type	Impact	CREP Stage 1 (1994-1996)	CREP Stage 2 (1996-1999)	CREP Stage 3 (2000-2004)	CREP Stage 4 (2005-2012)	CREP Stage 5 (2012-present)
Rearward Facing Infant	Front	P3/4 (9kg)	P3/4 (9kg)	P3/4 (9kg)	P3/4 (9kg) or P1 ½ (11kg)*	P3/4 (9kg) or P1 ½ (11kg)*
	Side	P3/4 (9kg)	P3/4 (9kg)	P3/4 (9kg)	P3/4 (9kg)	P3/4 (9kg)
	Rear/Inverted	Taru T [#] (4kg)	Taru T [#] (4kg)	Taru T [#] (4kg)	-	-
Forward Facing Child	Front	P6 (22kg)	P6 (22kg)	P6 (22kg)	P6 (22kg)	P6 (22kg)
	Side	P3 (15kg)	P3 (15kg)	P3 (15kg)	P3 (15kg) ⁺	P3 (15kg) ⁺
	Rear	P6 (22kg)	P6 (22kg)	P6 (22kg)	-	-
Booster (Type E) [^]	Front	P6 (22kg) or P10 (32kg)*	P6 (22kg) or P10 (32kg)*	P6 (22kg) or P10 (32kg)*	P10 (32kg)	P6 (26kg) ⁺⁺
	Side	P3 (15kg)	P3 (15kg)	P3 (15kg)	P6 (22kg) ⁺	P6 (22kg) ⁺
Booster (Type F) [^]	Front	-	-	-	-	P10 (32kg)
	Side	-	-	-	-	P10 (32kg) ⁺

*Choice of test dummy depended on maximum occupant mass specified by manufacturer. +Seated height modified to better represent seated height of children at upper end of restraint size range (P3 boosted to 605mm, P6 increased by 40mm).⁺⁺ P6 dummy weight is boosted to match upper mass range of Type E Booster. [^] A new type of booster was specified in the Australian Standard in 2010. # Taru Theresa.

The most important changes to the dummies occurred with the introduction of CREP 4 and were related to a realization that restraints on the market at that time (pre-2005) were often too small to accommodate the full size range of children to which they were marketed. This manifested, in many cases, as poor side impact protection, as the tops of the side wings of many restraints were below the seated height of the children using them. As shown in Table 2, the P3 dummy continued to be used to assess forward facing restraints, and the P6 to assess booster seats in CREP 4. However, the seated heights of these dummies were boosted to match the seated height of the upper age ranges of children using these types of restraints.

For booster seats, the size of the dummy used to assess performance in frontal impacts was reduced from the P10 in CREP 4 to the P6 in CREP 5. This occurred in response to manufacturers concerns that the P10 dummy is significantly bigger and heavier than the largest size of child for which these restraints were designed. There was evidence of this in CREP 4, with a few boosters observed to be unable to properly accommodate the larger dummy. Furthermore, since the primary objective of the booster is to improve seat belt geometry for small occupants who would not be adequately restrained by the belt without the booster, it was felt that the smaller P6 dummy would provide a more suitable assessment. However, the P6 dummy's weight is below that of the upper limit of the weight range of these restraints. Therefore, the P6 is weighted to match the upper limit of the mass range of Type E boosters, by adding material to the chest and pelvic areas. This is done to ensure there is good assessment of the structural integrity of these restraints in the frontal impact.

Performance assessment

The areas of performance assessed throughout the CREP history have remained relatively unchanged. Since its inception, the program has assessed a number of areas of performance common to all restraint types. These include structural integrity of the restraint and dummy retention. For rearward facing restraints there has always been an assessment of the restraint's ability to distribute crash loads across the back of the dummy. The need to distribute the crash forces in this way arises from concerns about the potential for neck injury resulting

from axial loading of the spine, particularly in young infants with their combination of a relatively large head and weak neck. Head displacement and head energy management (HIC 36) in frontal impact has always been assessed in rearward facing and forward facing restraints and head protection in side impact has been common across all restraint types throughout the entire history of the program. However, there have been changes in what restraints are subjected to these assessments and the way head protection in side impact is monitored. There have also been other areas of performance assessment added for some restraints, over time.

Head displacement and head energy management were originally assessed in all restraint types but these assessments were eventually dropped for booster seats as these measures were found to be heavily influenced by lap belt and sash strap position. Low head excursion occurs when there is submarining. Although low head excursion is desirable, submarining in booster seats is not.

In the original Stage 1 of CREP, head protection in side impact was monitored in two ways. Firstly there was an assessment of whether or not the dummy's head was allowed to strike the side door structure, and secondly HIC 36 was used to gauge the severity of the impact between the dummy's head and the door structure. The head strike assessment has been continued through the subsequent stages of CREP to the present time, and retention requirement that restraints must prevent a head strike with the side door structure was included in the Australian Standard in 2004. In 2010, the Standard was revised to require that no observable part of the dummy head could be within 10mm of the door. No attempt was made to assess head injury management in side impact during the early stages of the CREP due to the non-uniform stiffness of the original door structure. However, HIC 36 values continued to be routinely collected to monitor the severity of head impacts and to gain an indication as to whether any meaningful energy attenuation measures were being implemented by manufacturers.

Following the introduction into the Australian Standard of the side door structure and the requirement for all restraints to prevent head to door contact, all devices coming onto the Australian market began to provide some degree of head containment. To capture the variability in the degree of head containment that was being observed, CREP Stage 4 introduced a graded score of this performance. As described by Brown et al (2007), the highest score is given if the head remains completely within the confines of the side wings and a low score is given if the head becomes exposed over the rim of the side wings. A '0' score is assigned to head contact with the door.

Assessment of side impact head energy management was introduced for CREP 5, using HIC 36 as the assessment criteria. This required the introduction of a new side door structure with uniform stiffness.

Significant additions to the assessment of booster seat performance were also made in CREP 4. As described by Brown et al, (2007) the assessment procedures introduced in CREP 4 placed a high priority on the ability of a booster seat to provide the test dummy with good seat belt geometry and for the dummy's upper torso to remain satisfactorily restrained throughout the impact. Assessments were therefore included for the pre-impact seat belt sash strap geometry on the dummy and for the maintenance or otherwise of good sash strap and lap belt geometries during impact. Similar assessments were subsequently incorporated into AS/NZS 1754:2010.

Scoring Systems

In CREP 1 and 2, "Preferred Buy" ratings were given to a number of devices in each category that were rated as performing well in a number of pre-defined areas. However, the method used to make these judgments was subjective and there was little documentation of the protocols used. This led to a significant difference in how preferred buys were awarded in CREP 3. In CREP 3 evaluations were based mainly on technical compliance with requirements, and little weight was given to the more desirable features of performance used in making assessments in CREP 1 & 2.

To address this, an objective point scoring system for CREP was first introduced in CREP 4. The scoring system used in Stage 4 involved the use of a ratings matrix, using an approach derived from methods used in the ease of use assessment by the North American National Highway Safety Traffic Administration (NHTSA), and is discussed below.

Basically, the features assessed in the dynamic component were divided into a set of performance categories. Within each category, there were a set of items or individual performance aspects (PA). Each PA was given a weight between 1 and 4 based on the importance in terms of offering crash protection in the real world. A numerical scale of 4 (good) to 0 (unacceptable) was used to rate the outcome for each PA. Scores for each PA

were obtained by multiplying the outcome score by the weight for that PA. Category scores were calculated by adding the scores obtained for that category and calculating what percentage this was of the maximum possible score for that category. Initially, each category was then awarded an A, B, C or D ranking based on the breakpoints set out in Table 3 below.

These breakpoints were set on the basis that any device scoring less than or equal to 50% of the maximum score was judged as ‘unacceptable’ and given a ‘D’ ranking. The range between 50% and 100% was then divided into 3 equal ranks.

The overall score was calculated by averaging the sum of the normalised scores for each component. That is $[(\% \text{ score Frontal}) + (\% \text{ score Side 66}) + (\% \text{ score Side 90})/3]$. The overall score was then also awarded a ranking using the same breakpoints illustrated in Table 3. One limiting rule was also applied to category and overall rankings. This rule was that if any device receives two or more ‘0’ scores (i.e. an ‘unacceptable’) score, that device could not be awarded an A or B ranking for that category or for an overall ranking.

Table 3 Ranking Score Calculations – CREP Dynamic Testing

‘Performance Aspect’ Set Score	Overall Score
The ‘PA’ set score $\geq 83\%$ of maximum ‘PA’ scores that could be obtained for the set	The sum of the ‘PA’ scores $\geq 83\%$ of the sum of the maximum scores that could be obtained for all the ‘Performance Aspects’
The ‘PA’ set score $< 83\%$ but $\geq 67\%$ maximum ‘PA’ scores that could be obtained for the set	The sum of the ‘PA’ scores $\geq 66\%$ but $< 83\%$ of the sum of the maximum scores that could be obtained for all the ‘Performance Aspects’
The ‘PA’ set score $< 66\%$ but $\geq 50\%$ of maximum ‘PA’ scores that could be obtained for the set	The sum of the ‘PA’ scores $\geq 50\%$ but $< 66\%$ of the sum of the maximum scores that could be obtained for all the ‘Performance Aspects’
The ‘PA’ set score $< 50\%$ of maximum ‘PA’ scores that could be obtained for the set	The sum of the ‘PA’ scores $< 50\%$ of the sum of the maximum scores that could be obtained for all the ‘Performance Aspects’

While the scoring system introduced in CREP 4 was relatively successful in providing comparative ratings of restraints on the market, some child restraint systems were observed to perform unexpectedly poorly in some important areas. Some of the observed failures were not anticipated when the CREP 4 protocols were introduced and the resulting ratings did not adequately reflect their poor performance. The lack of a ‘balancing’ feature in calculating the overall score from the component dynamic tests also added to the problem. Poor performance in one of the dynamic tests e.g. side impact could be masked by very good performance in the other tests e.g. frontal impact.

The scoring system was then modified and the revamped system introduced part way through CREP 4. It has not changed since. This new method has three important characteristics; 1. The assessment of performance in three different test orientations are combined into a single group of assessments; 2. A number of critical performance areas were identified where poor performance in one of those areas limits the overall score, and 3. A 5 star rating system replaces the 4 category A-D ranking system.

The method of calculating an overall score by averaging the sum of the normalized scores from each of the three dynamic tests was therefore abandoned and this addressed the need for any ‘balancing’ feature. As shown in Table 4, the three dynamic tests continued to be included and scored individually. However performance aspects that are common to two or more tests are grouped into a single score, with the lowest score in any test used in the ratings. Performance aspects that are not common across two or more tests are kept as separate items, with two exceptions. These are ‘Head Retention’ for forward facing seats and boosters; and dummy

retention in booster seats. While the assessment of ‘Head Retention’ for forward facing seats and boosters is common to both side impact tests, restraints often demonstrate very different performance in the two tests.

Table4.
Assessment features in the combined scoring system introduced during CREP4

Rearward facing infant restraints	Forward facing child restraints	Booster Seats
Head Retention - Front & Side Impact Testing*	Forward Head Excursion – Frontal Impact Testing*	Seat Belt Sash Strap Location - Frontal Testing
Dummy Retention - Front & Side Impact Testing*	Forward Knee Excursion – Frontal Impact Testing	Head Retention – 90 Side Impact Testing
Upward and/or Rotational Displacement of the CRS in Rebound – Frontal Impact Testing	Head Retention – Frontal and Side Impact Testing	Dummy Retention – Frontal Testing*
CRS Security and Integrity - Front & Side Impact Testing*	Dummy Retention - Front & Side Impact Testing*	Dummy Retention 90 Side Impact Testing
Load Distribution - Frontal Impact Testing	CRS Security & Integrity - Front & Side Impact Testing*	Head Energy Management -Side Impact Testing with the seat belt sash strap over the shoulder adjacent to the <i>Side Impact Door</i>
Head Energy Management - Frontal Impact Testing	Operation of Quick Release Device – Frontal Impact Testing*	Submarining - Frontal Impact Testing
Head Energy Management -Side Impact Testing*	Head Energy Management - Frontal Impact Testing	CRS Security & Integrity - Front & Side Impact Testing*
Torso Energy Management - Frontal Impact Testing	Head Energy Management - Side Impact Testing	
Adjuster Slip - Front & Side Impact Testing*	Torso Energy Management - Frontal Impact Testing	
	Upward Displacement of CRS in Rebound - Frontal Impact Testing	
	Adjuster Slip - Front & Side Impact Testing*	

Good performance in a 90 degrees test would almost certainly be negated by universally poor performance in the 66 degrees tests. Therefore, a decision was made to continue to treat these separately. Similarly, dummy retention in booster seats is quite often starkly different between frontal and side impact testing. Therefore, dummy retention in frontal impact continues to be treated differently from dummy retention in side impact.

In this new method of scoring the overall performance, the overall score is calculated by taking the sum of points achieved divided by the maximum number of possible points and expressing this as a percentage.

A number of performance aspects have been nominated as critical features to ensure extremely poor performance in any of the tests is adequately captured. If a restraint scores a 0 in any one of the critical features (highlighted with * in Table 4) the restraint is limited to a 1 star rating.

The five star rating system was achieved by dividing the range of scores between 50 and 100. This resulted in the following breakpoints:-

- 5 stars – $\geq 87.5\%$
- 4 stars – $\geq 75\% < 87.5$
- 3 stars – $\geq 62.5\% < 75\%$
- 2 stars – $\geq 50\% < 62.5\%$
- 1 star – $< 50\%$

OBSERVED IMPROVEMENTS IN CHILD RESTRAINT SYSTEM PERFORMANCE

There have been a number of important and quite clear improvements in child restraint performance observed over the course of the CREP. The most important of these have been the improvements in side impact protection provided by forward facing seats and booster seats, and the performance of booster seats in frontal impact. As detailed below these have largely occurred following significant enhancements in restraint design.

Side impact protection

In the first series of the CREP (Stage 1), 40% (4/10) of forward facing restraints and 100% (5/5) of the high back booster seats, allowed a head strike. This was despite the fact that in this test series there was no increase in the seated height of the dummies to match the upper limit of the seated height range of children who would be using the restraints. An improvement in side impact protection is evident from review of the results coinciding with the beginning of CREP Stage 4 and the boosting of the dummy seated heights.

In the first series of CREP 4 (4a), most forward facing restraints and high back booster seats allowed head contact with the door. While this poor performance continued for most of CREP Stage 4 there was some improvement observed, see Figure 1. However, by CREP 5 no head contact with the side door occurred in any restraint in the 90° tests.

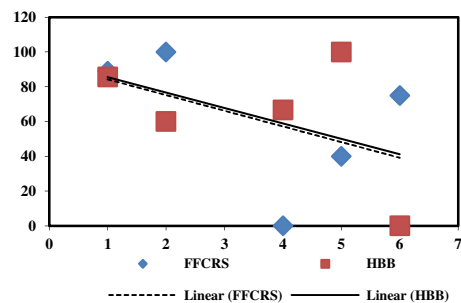


Figure1. Performance of restraints in each series of CREP 4 from CREP4a (1) to CREP 4B (2) shown as percentage of restraints that allowed head contact with side door in each series. FFCRS - Forward facing child restraint; HBB – High Back Booster



Typical side wing height change on FFCRS over CREP4-CREP5



Typical side wing height change on HBB over CREP4-CREP5

Figure2. Typical changes in side wing height in forward facing child restraints (FFCRS) and high back boosters (HBB) from CREP 4 (2005-2012) to CREP 5 (2012-)

As shown in Figure 2, the driver in these improvements is an increase in side wing height in both forward-facing child restraints, and high back booster seats. The movement towards higher side wings is likely to be a result of the combination of the adoption of the CREP side impact test procedure and a similar assessment method into the Australian Standard in 2004 together with additional requirements included in the Standard for minimum seat back heights for all restraint types in 2010. The restraint dimension requirements were written to support laws requiring appropriate restraint use by Australian children. Restraint back and (for rearward & forward facing restraints) shoulder harness slot heights were defined to ensure that forward facing restraints could accommodate children up to the 95th percentile 4 years old, and booster seats could accommodate children up to the 95th percentile 8 year old.

Frontal crash protection in booster seats

The ability of high back booster seats to provide good seat belt geometry and to maintain good torso restraint during frontal impact began to be assessed in CREP from Stage 4. Results from the first 17 high back booster seats from these assessments have been published previously (Brown et al, 2009). As described by Brown et al (2009), 10 of the 17 (59%) demonstrated static lap belt positions low down on the dummy abdomen, adjacent to the dummy thighs, and only 5 of the 17 (29%) boosters were able to maintain good lap belt positioning throughout the frontal impact. Furthermore, Brown et al (2009) noted a wide variation in the static position of the sash part of the belt in these boosters, with only two restraints positioning the sash over the mid-shoulder region of the dummy, and contact between the sash belt and the dummy shoulder was maintained during the impact in only 9 of the 17 boosters (53%).

The results presented by Brown et al (2009) represent the first half of the CREP 4 test series, and as shown in Figure 3, some improvement was beginning to be observed by the end of CREP 4. Fifteen boosters were tested in the second half of CREP 4, good lap belt positioning was maintained in 8 of the 15 boosters (53%) and contact between the sash belt and dummy shoulder maintained in 13/15 boosters (87%).

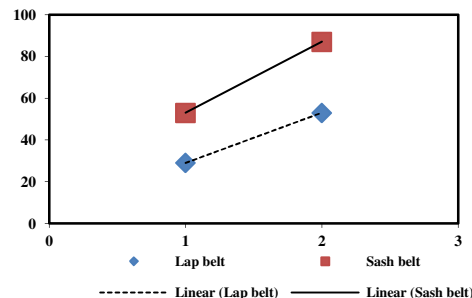


Figure3. Percentage of boosters maintaining good lap belt and sash belt position during dynamic frontal testing in the first half (1) and second half (2) of CREP 4 (2005-2012)

Requirements related to the static pre-impact position of the lap belt were included in the Australian Standard in 2010 – and more recently knee excursion limits have been added as a defacto measure of submarining. (2013). This means that all booster seats now sold on the Australian market must demonstrate the ability to provide good lap belt positioning and minimize submarining in frontal impact testing.

As described above, the dummy being used to assess most booster seats was changed to the P6 in CREP Stage 5. In CREP 5 there has only been one booster that has failed to maintain good lap belt position using the P6 dummy, and all have demonstrated an ability to maintain contact between the sash belt and the shoulder throughout testing.

AREAS IDENTIFIED FOR FURTHER IMPROVEMENT IN RESTRAINT PERFORMANCE

While there have been some notable improvements in performance as described above, some issues of concern remain. These include the level of side impact protection for the head and load distribution management in frontal testing in rearward facing restraints and head protection in forward facing restraints during rebound in frontal testing.

Head protection in side impact in rearward facing restraints

Head energy management assessment in side impact commenced in CREP 5. This involves the use of HIC36 to comparatively assess how well restraints attenuate energy once the dummy's head is contained within the side structure of the restraint in the 90° impact. As shown in Figure 4, there are some substantial variations being observed in how well different restraints appear to be able to do this. It is unknown whether the variations in performance being observed reflect any variation in performance in the real world, but the magnitude of the differences suggest this may be an area worthy of further investigation

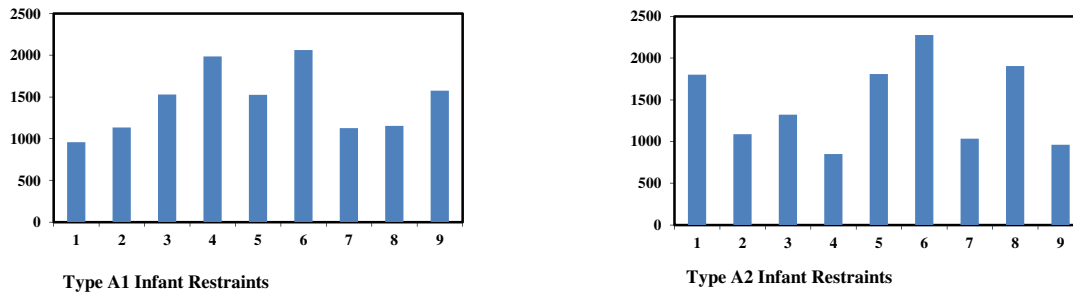


Figure4. HIC36 measured in 90° side impact with TNO P3/4 (Type A1) & TNO P1 ½ (Type A2)

Distribution of crash load in rearward facing restraints

Another area of concern in the performance of rearward facing restraints is their ability to distribute the crash load over the back of the dummy. A primary design goal of a rearward facing restraint should be to distribute most of the load in a frontal crash through the back of the head and torso. The Australian Standard carries a note to this effect, and as such it is not a mandatory requirement of the Standard. This feature has been assessed in CREP since its inception by calculating the force distributed through the back of the torso as a percentage of the force along the longitudinal axis of the torso. The larger the value, the better the restraint is in achieving the design goal. Figure 5 illustrates the results achieved by rearward facing restraints tested during CREP 5. There is clearly one restraint that is substantially superior in being able to distribute the greater proportion of the load through the back of the dummy. Significantly, 17 of the 27 (63%) of the restraints tested to dated in CREP 5 have not been able to do so. Again the effect this is having in the real world is currently unknown, but the results indicate further investigation is warranted.

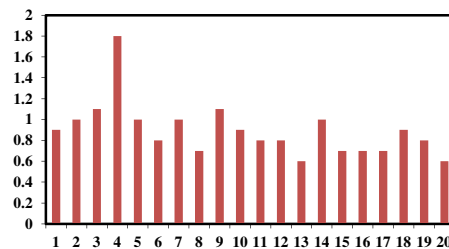


Figure5. Performance of rearward facing restraints in distributing crash loads over back of dummy head and torso in frontal impact (from CREP 5)

Head protection in forward facing restraints during rebound

While we have seen significant increases in the height of the side wings in forward facing restraints, and the full height of the side wings being comprised of structurally robust material, there appears to have been a tendency for manufacturers to not extend this height/structural integrity to the back of their restraints. In CREP 5, the behavior of the dummy's head during rebound in frontal testing has been assessed in forward facing restraints. This has captured a previously unreported potentially poor aspect of performance of many modern forward facing restraints. This involves the dummy's head being allowed to rotate over the top of the seat back (see Figure 6). This occurs in restraints where the height of the restraint back reduces between the side wings, as well as in restraints where the material at the top of the seat back fails to adequately support the dummy's head. The latter has commonly been seen in restraints incorporating internal adjustable head restraints (see Figure 6).



Head rotates overs 'dip' in seat back No structural support at top of back Head rest fails to support head
Figure6. Poor support of dummy head in rebound during frontal impact

AREAS IDENTIFIED FOR FURTHER ENHANCEMENT OF THE SCORING PROTOCOLS

On the introduction of an objective point system based assessment method in CREP 4, the focus for booster seats was primarily on the ability of boosters to achieve their primary design goal of improving seat belt geometry for the children using them. As described above, there have been substantial improvements in this regard in boosters introduced onto the Australian market over the last decade or so. There have also been significant enhancements to the Australian Standard related to the required levels of performance in maintaining good seat belt geometry in frontal impact. Changes made to the booster seat protocols prior to CREP 5 in response to the modifications made to the Australian Standard, may have left the protocols needing more refinement to better communicate variations in performance beyond that related to front impact protection.

Some boosters are performing in a far superior manner to others in containing the dummy's head in side impact and managing the energy, as measured by HIC36 (see Figure 7). Currently, the scoring system being used in CREP 5 is not capturing this variation in performance as well as it might. Five star boosters should be expected among the higher performing restraints in all aspects, and as shown in Figure 7, one restraint in particular has measured HIC >1000 in side impact but has still managed to score a 5 star rating. Similarly there are two restraints that have measured HICs among the highest values seen in this series and these restraints have still managed to score 4 stars. Further refinements of the assessment and scoring protocol are planned to try to adequately capture this type of performance in ratings. Moreover, consideration is being given to making the head energy management in side impact a critical feature. In that way this type of poor performance would limit the overall score the restraint could achieve. It is important that manufacturers be encouraged to seriously consider the energy attenuation provided by their restraint systems in side impact.

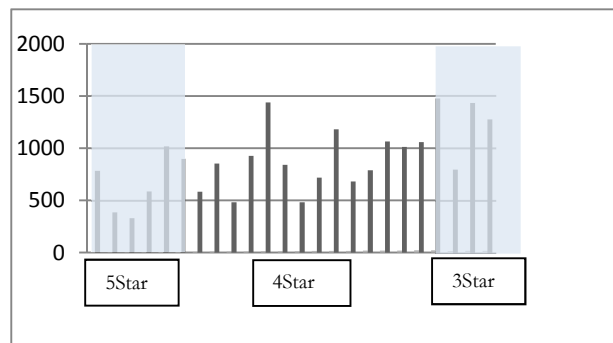


Figure7. Head energy management as measured by HIC36 in boosters in side impact in CREP 5

CONCLUSIONS

The Australian CREP program has evolved dramatically over the last 20 years. It is now a comprehensive and objective rating system providing important advice to consumers about the performance of restraints beyond the minimum performance level required by the Australian Standard for child restraints.

There have been innovative test methods and assessment procedures incorporated into the CREP since its inception and these have continued to evolve with the program. In addition to providing consumers with important information and encouraging manufacturers to continually improve their products, the CREP has also driven improvement in the minimum performance required by the Australian mandatory product Standard. Together, this has worked to influence some dramatic improvements in the performance of child restraints now available on the Australian market. This is most notably seen in the head protection provided in side impact in forward facing restraints and high back boosters; and the performance of high back boosters in frontal impact.

The program also continues to highlight emerging areas of concern. Currently this includes the head protection provided by rearward facing restraints in side impact, the inability of rearward facing restraints generally to adequately distribute crash forces in frontal impact, and the tendency for poor head containment in forward facing restraints during rebound in frontal testing. While it is clear that there are substantial variations in performance of restraints currently on the market in these areas, the impact of this on the real world crash protection of children remains unclear. Further investigation is warranted.

Finally, there may be some aspects of poor performance still not adequately being captured by the current protocols and work continues to further enhance the protocols.

REFERENCES

- Bilston, Lynne E, Brown, Julie, & Kelly, Paul. (2005). Improved protection for children in forward-facing restraints during side impacts. *Traffic injury prevention*, 6(2), 135-146.
- Brown, Julie, Kelly, Paul, Suratno, Basuki, Paine, Michael, & Griffiths, Michael. (2009). The need for enhanced protocols for assessing the dynamic performance of booster seats in frontal impacts. *Traffic injury prevention*, 10(1), 58-69.
- Brown, Julie, Paine, Michael, Paine, David, Kelly, Paul, Griffiths, Michael, Magadera, Nimmi, Soames, J. (2007). *Revised assessment protocols and scoring methods for the Australian Child Restraint Evaluation Program*. Paper presented at the 20th Enhanced Safety of Vehicles Conference, Lyon.
- Kelly, P, Griffiths, M, Booth, M, Lemon, J, Crothers, N, & Franks, C. (1996). *Child restraint evaluation program*. Paper presented at the Proceedings: International Technical Conference on the Enhanced Safety of Vehicles.