Euro NCAP Whiplash Test Procedure - A New Consumer Seat Rating Programme

Matthew Avery, Edward Giblen, Alix Weekes
Thatcham, UK

ABSTRACT

The Consumer rating organisation Euro NCAP has been developing a whiplash test procedure. The group analysed the current rating programmes from the IIWPG (International Insurance Whiplash Prevention Group) and from SRA (the Swedish Road Administration) and Folksam. The development of the procedure has included proving the repeatability and reproducibility of the procedure in order to prepare for its incorporation into the consumer testing program. The dummy set up and test pulses have been proven to be repeatable and reproducible. A rating system has been developed to aid consumer understanding. The initial testing series of 25 seats is complete and a wide range of results is achieved, indicating that some seats still need improvement to protect car occupants from whiplash injury.

Keywords: Whiplash, BioRID, Protection, Seats, Head Restraints

INTRODUCTION

The whiplash cost burden is not limited to the motor insurers, but also those who purchase motor insurance and the wider society in general. British insurers report a cost in excess of €3 billion annually in the United Kingdom due to whiplash (1). In Sweden 70% of all injuries leading to disability are due to whiplash injuries (2). Whiplash most commonly occurs during rear impacts, and is the most commonly reported injury in crashes (3). Statistics from the Comité Européen des Assurances (4) show that four countries have a very high rate of claims for whiplash injuries, including the United Kingdom (76% of bodily injuries), Italy (66%), Norway (53%), and Germany (47%). Switzerland has the highest average cost per claim linked to cervical trauma (4) with approximately €35,000 per claim, followed by the Netherlands (€16,500), and Norway (€6,050). Although most people recover from whiplash injury, around 10% of people suffer over a longer period (5,6,7).

The vehicle seat and head restraint have been shown to be the principle means of reducing neck injury (8). There were two existing procedures for testing seats and head restraints for the protection they offer against whiplash injury. These procedures were from the International Insurance Whiplash Prevention Group (9), and from the Swedish Road Administration (10,11,12,13). In 2003 Euro NCAP began looking at Whiplash with the intention of adding a test to the current occupant protection ratings derived from three whole vehicle crash tests. The whiplash test procedure thus defined combines the two established procedures into a more comprehensive one. This paper describes the new Euro NCAP whiplash assessment test procedure. The Euro NCAP points rating system is also presented, and some initial testing results.

HISTORICAL DEVELOPMENT OF WHIPLASH TESTING

Research has shown that reducing the distance between the head and head restraint can reduce whiplash injury risk (8,14,15). A static geometric evaluation of head restraint geometry was established by RCAR (Research Council for Automobile Repairs), to encourage positioning of head restraints closer to the driver's head. Subsequently the International Insurance Whiplash Prevention Group (IIWPG) was formed in 2001 with the aim of developing a dynamic testing procedure to investigate seats under dynamic loading (9). This procedure was designed to encourage seat and head restraint characteristics proven in the real world to reduce whiplash injury. This 'best practice' approach aims to promote designs that will support the head early and/or absorb energy so that the differential movement between the head and neck is reduced, and hence the risk of whiplash injury is reduced. The 16 km/h delta-V triangular test pulse is derived from real world crash data and is representative of a crash where whiplash injuries would occur as shown in Linder et al. (16). In 2003 Folksam and the Swedish Road Administration (SRA) started testing of car seats, where each seat is exposed to three different tests (10,11,12,13). One of the pulses is the same 16km/h delta-V triangular pulse used in insurance tests. The other two pulses were trapezoidal and simulate a 'low' 16 km/h delta-V (peak 5g), and 'high' 24 km/h delta-V (peak 7.5g). The Folksam/SRA test procedure uses injury criteria values proposed by several institutions, but as yet unproven to relate to actual injury mechanisms; however they do encourage similar seat characteristics as the IIWPG test e.g. energy absorption, and head restraints that are close to the occupant's head.

Recent studies have shown a correlation between whiplash consumer crash testing and real-world injury outcome (17,18). Both these studies indicate that a seat with a Poor (or Red) rating have a higher risk of whiplash injury compared with seats rated as Good (or Green Plus).

EURO NCAP WHIPLASH TEST PROCEDURE

Since 2003 Euro NCAP has been developing a whiplash seat assessment system to enhance its occupant protection star rating system. With no significant advance in knowledge of the injury mechanisms of whiplash, and little difference shown in real world performance of the two existing test procedures (17), the proposed Euro NCAP test (19) is effectively a combination of the IIWPG and SRA procedures. It uses three test pulses, the triangular IIWPG pulse, (common to both IIWPG and SRA systems), combined with the other two SRA trapezoidal pulses. So these three pulses are termed 'medium' (16km/h IIWPG), 'low' (16km/h SRA), and 'high' (24km/h SRA) within the Euro NCAP whiplash scheme. This scheme has been shown to give points scores that correlate with the existing IIWPG and SRA ratings systems (20).

The seats are mounted on the sled to a standardised method that approximates the basic geometry of the subject vehicle. The seat mount brackets replicate the correct seat rail angle and distance to the floor pan of each subject vehicle. The seats are set to achieve a 25º torso angle of the H-point manikin fitted with an HRMD. The test procedure requires static geometric measurements prior to dynamic testing. A modified SAE J826 H-point manikin is employed combined with the Head Restraint Measuring Device (HRMD) (21,22) and is used to to define the H-point, head restraint geometry and other parameters used in set up of the test dummy.

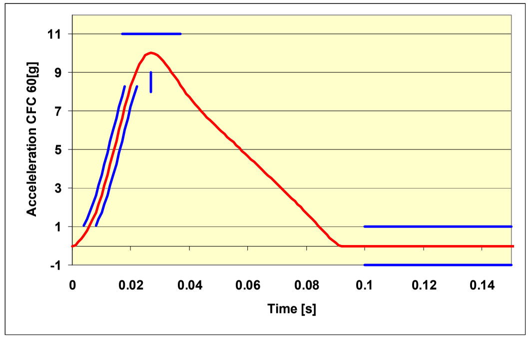

Figure 1 Medium pulse 16km/h (IIWPG).

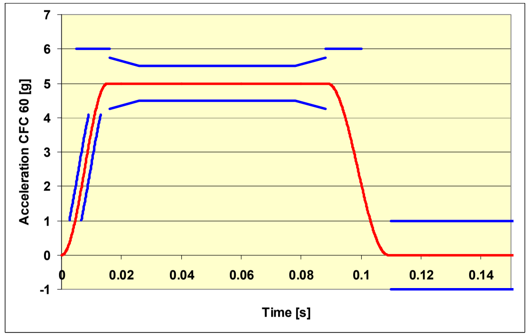

Figure 2 Low pulse 16km/h (SRA).

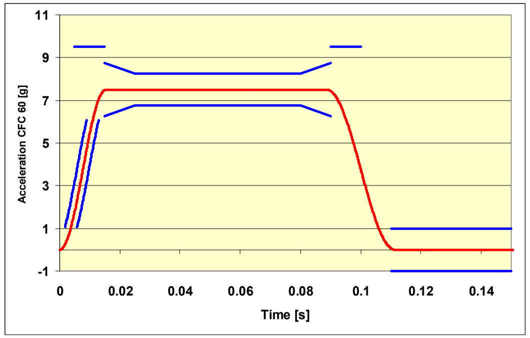

Figure 3 High pulse 24km/h (SRA).

			Medium Severity Pulse		Lower Severity Pulse		Higher Severity Pulse	
Characteristic		**Unit**	Requirement	Limits +/-	Requirement	Limits +/-	Requirement	Limits +/-
Delta-V	dV	km/h	15.65	0.8	16.1	0.8	24.45	1.2
Duration	dT	ms	91	3	105.8	3	107.7	3
Mean acceleration	Amean	m/s2	47.85	4	42.35	4.5	63.15	4.85
Acceleration at T0	AT0	m/s2	0	2.5	0	2.5	0	2.5

Table 1 Test pulse requirements and limits for medium, low and high pulses.

		Medium Severity Pulse			Lower Severity Pulse			Higher Severity Pulse		
Criteria	**Units**	Higher performance limit	Lower performance limit	Capping Limit	Higher performance limit	Lower performance limit	Capping Limit	Higher performance limit	Lower performance limit	Capping Limit
NIC	m2s-2	11.00	24.00	27.00	9.00	15.00	18.30	13.00	23.00	25.50
Nkm	-	0.15	0.55	0.69	0.12	0.35	0.50	0.22	0.47	0.78
Head rebound velocity	ms-1	3.2	4.8	5.2	3.0	4.4	4.7	4.1	5.5	6.0
Fx upper	N	30	190	290	30	110	187	30	210	364
Fz upper	N	360	750	900	270	610	734	470	770	1024
T1 acceleration up to head contact	g	9.30	13.10	15.55	9.40	12.00	14.10	12.50	15.90	17.80
Head restraint contact time	ms	57	82	92	61	83	95	53	80	92
Seatback deflection assessment	degrees	n/a			n/a			32		

Table 2 Sliding scale higher and lower performance limits for medium, low and high severity pulses.

For the dynamic test the head restraint is positioned in mid vertical and horizontal position where locks are fitted. If no locking is present under the definition of the test procedure then the most down and rear position is used depending on the plane of the lock, The BioRID (version IIg) is seated according to positioning data from the static measurements. Three individual tests are run using new identical seats using each of the three pulses. Assessments are also made as to the stability of the seat back during the “High” pulse.

The procedure uses seven variables: head restraint contact time, T1 x-acceleration, upper neck shear force, upper neck tension force, head rebound velocity, NIC, and N_{km}. Each seat is tested in the medium, low, and high pulses in turn. The test pulses are defined in Figures 1-3, and Table 1, and these have been updated from (20) with the final test pulse corridors defined as per the Euro NCAP procedure (19).

To prepare the Euro NCAP procedure for a consumer testing programme that could be undertaken at a variety of European laboratories and test houses, it was necessary to prove the repeatability and reproducibility of the protocol.

REPRODUCIBILITY OF TESTING

Reproducibility of Static Geometric Measurements

The test procedure involves the definition of seat geometry and ATD seated position. The repeatability and reproducibility of the static definition is fundamental to the testing process. For these reasons, the static measurement will have significant influence on the dynamic test result.

Statically, measurements may differ due to variations in set up process, variations in measuring equipment, and production variation in the seat itself. Static measurement variation can be characterised both in terms of its repeatability and reproducibility using individual seats, and also across a production batch of seats.

The static measurement process within the Euro NCAP protocol is a development of the RCAR procedure (23). Within both protocols, head restraint geometry is defined by height and backset and is achieved after setting the seat and installing the SAE manikin and HRMD in a closely prescribed manner.

In order to understand and control the potential variations in testing, an inter-laboratory harmonisation process was begun in 2006. Accredited Euro NCAP laboratories from the frontal, side and pedestrian test programmes were invited to participate. Thatcham’s involvement was due to its history in whiplash research, and in addition the participating laboratories were ADAC, BASt, IDIADA, TNO and UTAC. Five seat models were used in the study and a set of control measurements had been previously taken on each of the individual subject seats at Thatcham. Within these measurements each individual seat exhibited a different degree of variability by design.

The control measurement was used as a comparator for each of the participating laboratories and clear distinction between the control measurement and static measurements at different laboratories was observed. In certain laboratories, backset and height could be matched within 5mm variance from the control measurements, as shown in Figure 4. Elsewhere, the typical variance was between 10mm and 15mm, with up to 25mm observed maximum. In most cases, differences in the static measurements could be attributed to process issues relating to the seat set up and installation of the manikin. One typical issue noted within this phase was that the build condition of the SAE manikin was often away from the RCAR standard, i.e. with head room probe still attached. Secondly, the installation process was frequently not followed exactly, adjustments being made to seat position mid process, and either excessive or inadequate forces and support being applied such that a consistent H-point position was not achieved.

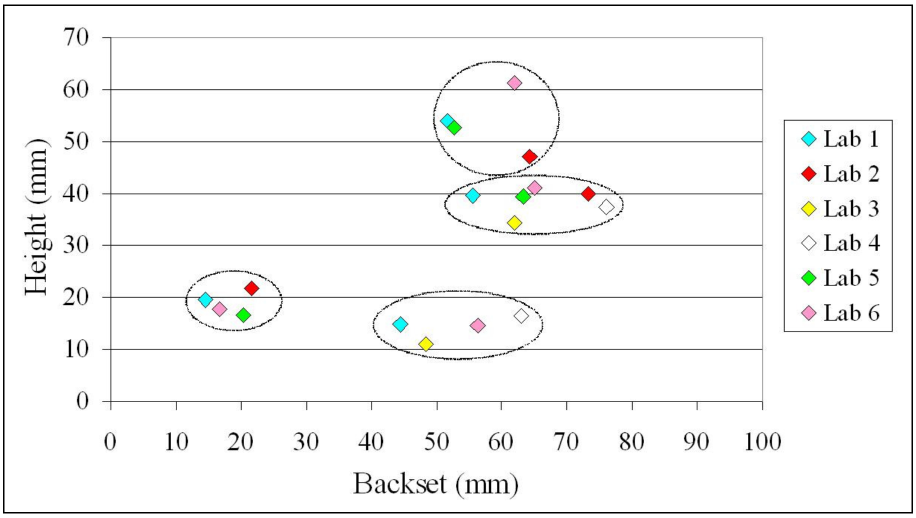

Figure 4. Static harmonisation – Initial phase: Comparison with control measurements at Lab 1 (average of all measurements)

To improve the static repeatability, various process controls were introduced and a new calibration process for the SAE manikin and HRMD was defined (24). It was subsequently found that with calibrated equipment, and closely controlled installation process, more repeatable measurements could be obtained.

The accuracy of each manikin installation can be initially quantified by measuring the positional differences between the left and right-hand H-points. This left to right difference in the X- and Z-directions represents the “skew” of the seated manikin. Control of permissible “skew” ensures that it is sat vertically, and installed “in line” with the seat.

The Euro NCAP whiplash test protocol calls for three measurements on each individual seat and specifies maximum permissible skew on each installation, plus a maximum variation between the three drops. Consequently, static repeatability is controlled and dynamic variation due to a single outlying static measurement is rendered unlikely.

In the final phase of harmonisation, three examples of a further seat model were measured by each laboratory. In accordance with the draft protocol, three measurements were taken on each seat. Across four of the participating laboratories, the average backset and height could be controlled within a window of 2mm variation in both measurements, as shown in Figure 5. It was also apparent that the equipment or installation process at two of the participating laboratories had achieved measurements clearly different from the others. While detail investigation was not undertaken into these outlying measurements, it is clear that where the protocol is followed exactly, repeatable and reproducible static measurements can be obtained.

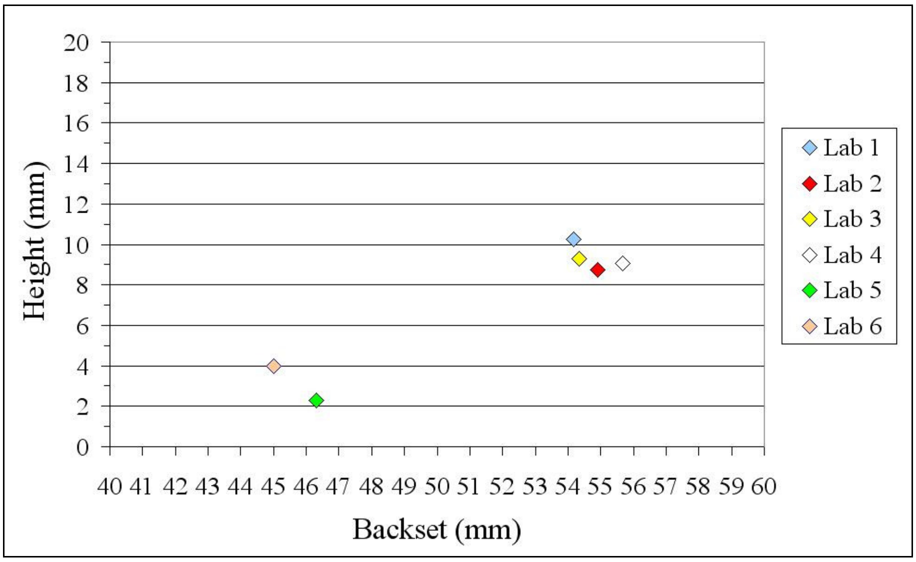

Figure 5. Static harmonisation - Final phase: Seat model "F" (average of 9 drops)

Pulse corridor – Time Indexing

While static geometry has an influence on dynamic ATD response, studies have also shown that differences in pulse shape effect the ATD response for a given seat test (25). Consequently, the pulse corridors were designed with initially stringent limits from the outset, with an intention to progressively relax limits as further knowledge was gained. The objective for the final corridor limits was to be sufficiently “inclusive”, without unduly compromising the repeatability or reproducibility of the test.

The six participating laboratories use differing types of test equipment, spanning various reverse acceleration sleds, and hydraulically braked stopping sleds. The pulse specifications were designed based on the known capability of the various sled types involved. Multiple examples of sled pulse data were submitted by each of the six participating laboratories.

Systematic differences exist between these facilities, and their effect on test results needs to be avoided. For example, since the test timebase depends upon the trigger levels for data acquisition, this should not be permitted to affect the head contact timing, and hence the points score obtained. To avoid any influence on the time base, a procedure to time index all data to a common point was adopted.

Every sled pulse was then individually time-offset, such that all data then passed through 1g at a common timing. The time indexed data was then used to derive a cosine-based equation which represented a nominal rise characteristic. If the process documented in the Euro NCAP whiplash protocol (19) is followed, a “time offset” value for any given test can be determined, and the windows for corridor compliance and data analysis can be predictably defined.

Pulse Corridor - Compliance

Literature suggests that Whiplash typically occurs at speeds around 16 Km/h (16). However real world data derived from Crash Pulse Recorders has shown that great variation in real world pulses that lead to injury can occur even where similar delta V’s were involved. Such a variation was however deemed inappropriate for a laboratory test so a variety of pre-defined pulses were chosen.

Very close control of both delta-V and peak g along with pulse duration was targeted since variation in these values can lead to reduced repeatability and reproducibility issues and variations in final scores of the same seat tested at different locations.

The acceleration corridors were designed to replicate the maximum level of control as demonstrated by the various laboratories using different equipment. This definition was reached after taking into account various designs of "reverse acceleration" type sleds ("pin-orifice" type, and later servo hydraulic), as well as hydraulically braked "stopping sleds".

During the process, a corridor on the leading rise was specified only 4 milliseconds wide. For the trapezoid pulses, a "plateau" corridor with moderate widening at each end was allowed, to account for the ability of some sled types involved to produce the angled elbow shapes in the pulse. Acceleration controls were applied to a time window before the start of the test, and another immediately following the end of the pulse. It was believed that these areas could affect the final result, either in terms of ATD pre-loading or position before test, or dynamic response during rebound. Additionally, these controls help to ensure that sled braking is significantly outside of the time window during which ATD criteria are assessed.

In addition to the acceleration corridors, the pulses are also controlled in terms of Delta-V (dV), mean acceleration (dA), and duration (dT). The limits specified for these three characteristics are more stringent than the acceleration corridor would suggest, i.e. a pulse passing through the acceleration corridors may potentially fail with DV, DT or DA since there is a direct relationship between the specified limits on all three criteria.

The final corridor specification was the result of a collaborative effort within all participating laboratories. The final version was accepted and signed off by all Euro NCAP laboratories as been realistically attainable using their own particular equipment.

EURO NCAP POINTS SCORING

The point scoring system is expected to be finalised in version 2.9 (26) of the procedure and it is described below.

Whiplash Raw Score

The Euro NCAP assessment uses a sliding scale system of points scoring, which involves two limits for each seat design parameter. Two performance limits (lower and higher) are set at the 70th percentile and 5th percentile respectively for values from (20). The more demanding higher performance limit below which a maximum score was obtained, and a less demanding lower performance limit above which no points were scored. The limits used in this test series are given in Table 2 for each of the seven measured variables for each test pulse, as per the final test protocol (19). The performance limits used were defined in an earlier 31 seat program undertaken jointly by Thatcham, Folksam and the SRA (20).

If the test value recorded falls between the lower and upper limits, the points score is calculated by linear interpolation. The score is 'capped' at the 95th percentile value from (20), meaning that if any single measured variable exceeded the 95th percentile limit, then a zero score is recorded for that test. If both head restraint contact time and T1 acceleration were worse than the lower performance limit and either one of these variables exceed the 95th percentile, then capping is applied and the score is also zero for that test.

The maximum score for each parameter is 0.5 points. For each of the pulses, the score for each of the seven parameters is calculated. The scores for the NIC, N_{km}, Head rebound velocity, neck shear and neck tension are summed together, plus the maximum score from either T1 acceleration *or* head restraint contact time. There is a maximum possible score of 3 points for each test pulse.

The points from each test pulse are summed together and modifier points applied. There are two assessments, and two modifiers. The assessments are static geometry and ease of adjustment. The geometry assessment aims to promote good static geometry between the head restraint and the occupants head. Similarly, the ease of adjustment assessment promotes seats that offer a means of ensuring that the head restraint is correctly positioned for different sized occupants without specific action from the occupant, other than simply adjusting the seat track position to suit the leg length. The modifiers are seat back dynamic opening and dummy artefact loading. The negative dummy artefact loading modifier can be applied to any seat that by nature of its design places unfavourable loading on any part of the dummy or exploits a dummy artefact. Finally, the seat back dynamic deflection modifier assesses the overall change in seat back angle in the High severity pulse only, to prevent occupant ramping and compromise of rear seat passenger space. The test points are combined with the assessment and modifier points (whether positive or negative) to form the Whiplash Raw Score.

Scaled Points

The scores for each of the test pulses are added together, creating a maximum dynamic test score of 9 points. The score is then subject to the various modifiers. From the modifiers a maximum of two more additional points are available, creating a maximum possible score of 11 points overall, which is the Whiplash Raw Score as shown in Figure 6. This overall score is then scaled to four points, which is the final score for the seat. The points are scaled to fit with the current Occupant Protection scoring to balance injury risk against threat to life. The total points currently available for the Adult Occupant Protection score is a maximum of 40, and the whiplash scaled points are a maximum of 4.

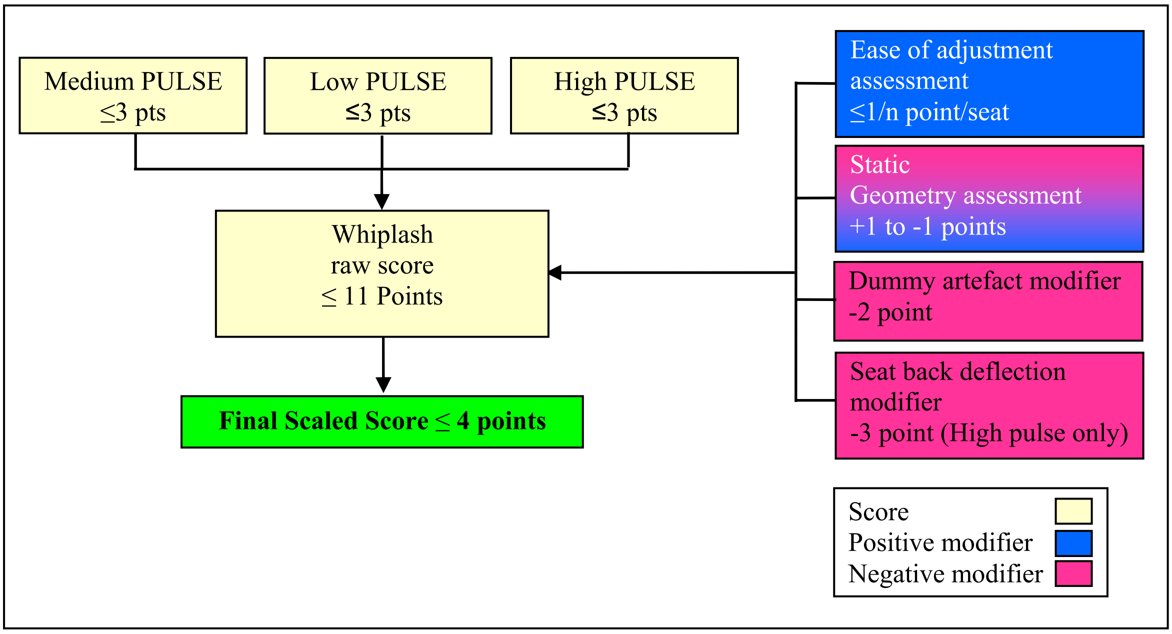

Figure 6 Euro NCAP proposed scoring scheme.

The final 4 point score is divided into three coloured bands as shown in Figure 7. A score of 0-1.49 is coloured 'Red' or Poor, a score of 1.50 to 2.99 is coloured 'Orange' or Marginal, and finally a score of 3.0 to 4.0 is coloured 'Green' or 'Good'. Three coloured bands are used for the whiplash points since this correlates to the resolution found in the analysis of real world whiplash claims. Studies of the existing whiplash test programs (17,18) have shown that Good and Poor seats can be clearly distinguished, but there is little resolution between Acceptable and Marginal rated seats in the real world. Euro NCAP chose to combine these two middle sections as one to reflect real world performance. The coloured bands are used as an additional indicator to raise public awareness and aid understanding of whiplash protection.

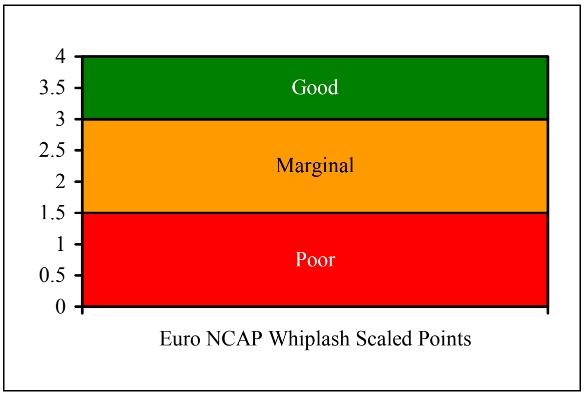

Figure 7 Euro NCAP Whiplash Scaled Points and Rating Bands

TESTING RESULTS

The initial round of testing was carried out during 2008, with 25 seats tested for publication in November 2008. Test results indicate that a wide range of points scores were achieved, ranging from 0 to over 3.5 points, as shown in Figure 8. It was found that some seats scored zero points, the minimum possible. These seats typically scored some points in certain criteria, but were capped due to exceeding of the 95th percentile value for one criterion. These seats are given a Red colour band to indicate to the consumer a poor relative whiplash protection.

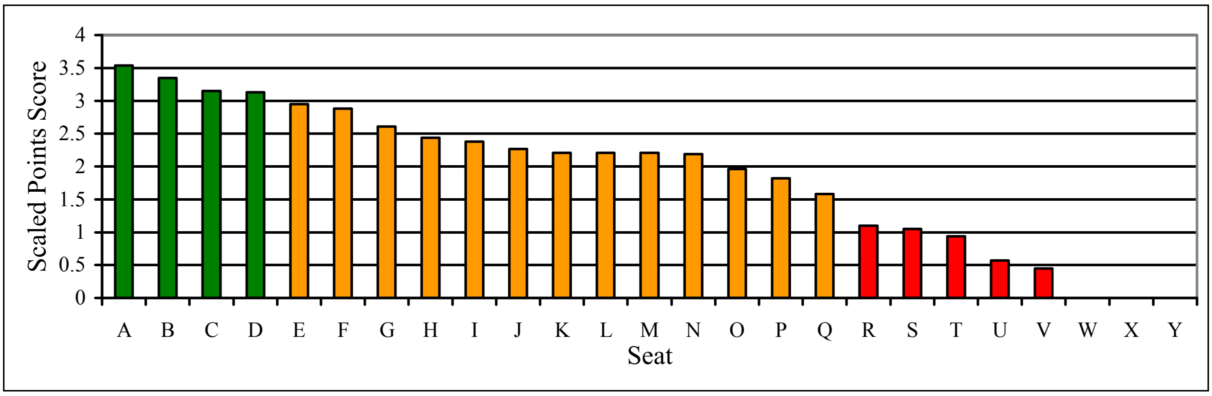

Figure 8. Scaled points scores for 25 seats

There were examples of seats scoring over 3 points. In these cases the seats tended to score over 2 points for each of the test pulses, then have positive modifier scores added. These seats therefore achieved Green colour ratings to indicate the higher level of protection afforded by these seats. These Green seats all featured certain "anti-whiplash" design characteristics shown to offer greater levels of protection in real world crashes. These anti-whiplash designs can involve energy absorption materials in the seat back, or mechanisms designed to move the head restraint forward to support the head and neck earlier and so limit the forces felt in the neck. Various studies (8,17,27) have shown that these designs can offer protection against whiplash injury in the real world.

DISCUSSION

The initial testing for Euro NCAP indicates that a wide variety of seats designs are in current production and that there is a large distribution in the scores achieved in the Euro NCAP test procedure. Some new models being launched and are able to achieve a score of over 3.5 (out of 4) ;a promising trend that illustrates that manufacturers are readily able to achieve high points scores using existing designs. However some new models are shown to score poorly, suggesting that these designs require development to offer improved whiplash protection. This initial testing provides a span of results from zero to over 3 points (over 75% of the available whiplash points) for new model seats that are representative of the range of new seats found in the real world (17,18).

Within the first phase it became apparent that consideration should be given by manufacturers as to the availability of positive modifier and assessment points, such as "ease of adjustment". Qualification for these points resulted in at least one manufacturer achieving a green rating since they help to ensure that a wide range of real world users are given protection from whiplash injuries.

Every green rated seat scores over 60% of available geometry points in this phase of testing. Every red rated seat conversely scores less than 20% of the available geometry points. This highlights the importance of geometry in seat design for manufacturers based on historical studies that link geometry to protection against whiplash injury (8,14,15).

Another trend revealed in the testing is that any seat dynamically achieving a capped score in any of the tests has a negative geometry points score. While negative geometry points are not necessarily a predictor of capped dynamic performance, a common trend was observed.

CONCLUSION

Development of the Euro NCAP test procedure has taken several years. The procedure has built upon existing whiplash testing programs. The development of the procedure has included proving the repeatability and reproducibility of the procedure in order to prepare for its incorporation into the consumer testing program. The dummy set up and test pulses have been proven to be repeatable and reproducible. The test procedure is now presented as version 2.8 (19), and is expected to be finalised in version 2.9 (26).

The Euro NCAP whiplash test procedure encourages best practice in vehicle design to prevent whiplash injuries. This is necessary since no injury mechanism for whiplash has been identified nor validated. The initial test results indicate that a wide range of results are possible, from 0 to over 3.5, confirming that some seat designs still need improvement for whiplash protection. Research will continue to monitor the effectiveness of the whiplash testing by Euro NCAP in the real world.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of the team of engineers at Thatcham, the support of Euro NCAP, and the co-operation of the vehicle manufacturers in supply of the car seats.

REFERENCES

1) Association of British Insurers (2008). Motor Insurance Claims Data. London, UK, Association of British Insurers.
2) Folksam (2005). How safe is your car? Stockholm, Folksam Research 10660 Stockholm Sweden.
3) Watanabe, Y., Ichikawa, H., Kayama, O., Ono, K., Kaneoka, K. and Inami, S. (2000). "Influence of seat characteristics on occupant motion in low-velocity rear-end impacts." Accident Analysis & Prevention **32** (2):243-250.
4) Comite Europeen Des Assurances (2004). Minor Cervical Trauma Claims: Comparitive Study. Brussels, Comite Europeen des Assurances.
5) Nygren, A. (1984). "Injuries to car occupants - some aspects of interior safety of cars." Acta Oto-Laryngologica **395**:1-164.
6) Nygren, A., Magnusson, S. and Grant, G. (2000). Nackskador efter bilolyckor Whiplash associated disorders. Lund, Sweden, Studentlitteratur.
7) Squires, B., Gargan, M.F. and Bannister, G.C. (1996). "Soft-tissue injuries of the cervical spine: 15 year follow-up." Journal of Bone and Joint Surgery **78B** (6):955-957.
8) Farmer, C.M., Wells, J.K. and Lund, A.K. (2003). "Effects of Head Restraint and Seat Redesign on Neck Injury Risk in Rear-End Crashes." Traffic Injury Prevention **4** (2):83-90.
9) Research Council for Automobile Repairs and International Insurance Whiplash Prevention Group (2006). RCAR-IIWPG Seat/Head Restraint Evaluation Protocol, Research Council for Automobile Repairs (RCAR) and International Insurance Whiplash Prevention Group (IIWPG). Version 2.5.
10) Folksam and Swedish Road Administration (2005). Pulse Calculation. Stockholm, Folksam and Swedish Road Administration.
11) Folksam and Swedish Road Administration (2005). Calculation of whiplash values. Stockholm, Folksam and Swedish Road Administration.
12) Folksam and Swedish Road Administration (2005). Standard test method for rear end impact crash tests. Stockholm, Folksam and Swedish Road Administration.
13) Krafft, M., Kullgren, A., Lie, A. and Tingvall, C. (2005). Assessment of whiplash protection in rear impacts. Stockholm, Folksam and Swedish Road Administration.
14) Chapline, J., Ferguson, S., Lillis, R., Lund, A. and Williams, A. (2000). "Neck pain and head restraint position relative to the driver's head in rear-end collisions." Accident Analysis and Prevention; special issue: Whiplash **32** (2):287-297.
15) Farmer, C., Wells, J. and Werner, J. (1999). "Relationship of head restraint positioning to driver neck injury in rear-end crashes." Accident Analysis and Prevention **31** (6):719-728.
16) Linder, A., Avery, M., Krafft, M., Kullgren, A. and Svensson, M. (2001). Acceleration pulses and crash severity in low velocity rear impacts - real world data and barrier tests. 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Amsterdam.

17) Kullgren, A., Krafft, M., Lie, A. and Tingvall, C. (2007). The effect of whiplash protection systems in real-life crashes and their correlation to consumer crash test programmes. 20th International Technical Conference on the Enhanced Safety of Vehicles, Lyon, France, 07-0468.
18) Farmer, C.M., Zuby, D. and Lund, A.K. (2008). Relationship of Dynamic Seat/Head Restraint Ratings to Real World Neck Injury Rates. World Congress on Neck Pain, Los Angeles, USA.
19) Euroncap (2008). The dynamic assessment of car seats for neck injury protection. Brussels, EuroNCAP. Version 2.8.
20) Avery, M., Giblen, E., Weekes, A.M. and Zuby, D. (2007). Developments in dynamic whiplash assessment procedures. Neck Injuries in Road Traffic and Prevention Strategies, Munich.
21) Gane, J. and Pedder, J. (1996). Head Restraint Measuring Device. 15th International Technical Conference on the Enhanced Safety of Vehicles Melbourne, Australia.
22) Gane, J. and Pedder, J. (1999). Measurement of Vehicle Head Restraint Geometry. SAE Congress, Detroit.
23) Research Council for Automobile Repairs (2001). A Procedure for Evaluating Motor Vehicle Head Restraints, Research Council for Automobile Repairs.
24) Avery, M., Zuby, D., Gane, J. and Cox, M. (2008). GLORIA: Design and Development of a Calibration Jig for H-Point Machines Used for the Measurement of Head Restraint Geometry. SAE 2008 World Congress, Detroit, 2008-01-0348.
25) Zuby, D.S., Farmer, C.M. and Avery, M. (2003). The influence of crash pulse shape on BioRID response. IRCOBI Conference 2003, Lisbon, Portugal.
26) Euroncap (unpublished). The dynamic assessment of car seats for neck injury protection. Brussels, EuroNCAP. Version 2.9.
27) Jakobsson, L. and Norin, H. (2004). AIS1 neck injury reducing effect of WHIPS (Whiplash Protection System). IRCOBI Conference 2004, Graz, Austria.