EEVC/CEVE

European Experimental Vehicles Committee

The Validation of The EEVC Frontal Impact Test Procedure.

Presented to the Fifteenth International Technical Conference on the Enhanced Safety of Vehicles, Melbourne, Australia, May 1996

Paper Number: 96-S3-O-28

THE VALIDATION OF THE EEVC FRONTAL IMPACT TEST PROCEDURE.

R W Lowne,
on behalf of EEVC Working Group 11
Paper Number 96-S3-O-28

ABSTRACT

The EEVC Working Group 11 proposed a new frontal impact test procedure, based on a partial overlap impact to a deformable faced barrier, at the 14th ESV Conference in 1994. This test procedure has been subject to a validation programme to evaluate the repeatability, reproducibility and the applicability of the test procedure to a range of passenger car types and sizes. It also considered the effect of an increase in the impact speed from 56km/h to 60km/h. As well as the European validation programme, parallel testing in support of the EEVC work has been performed in Australia, Canada, Japan and the USA.

This paper presents the results of the validation programme and the conclusions regarding the current recommendations for the EEVC front offset deformable impact test procedure.

INTRODUCTION

In 1990, the EEVC created a Working Group (WG11) with the objective of determining the most beneficial ways in which evaluation of the performance of vehicle in front impacts could be improved. It was concluded that modifications to the 'component' regulations were unlikely to produce a large effect. The greatest benefit was considered to be achievable through a new frontal impact test, more representative of the impact conditions of car-to-car front impacts. In the interests of improving the possibilities of future harmonisation of test procedures, the EEVC invited the participation of experts from the governments of the United States of America, Canada, Japan and Australia. In addition, experts from the automobile industries of Europe, the USA and Japan have provided advice to the Group.

The accident studies indicated the importance of intrusion in the production of fatal and serious injuries and demonstrated the importance of replicating, in the dynamic test, the dynamics of structural deformations occurring in accidents. It quickly became apparent that an offset impact into a deformable barrier greatly improved the replication of deformations in these accidents.

EEVC WG11 created a test programme designed to enable the development of a test procedure that would achieve the objectives. The test programme selected car-to-car impacts between three different vehicle models as the baseline and compared car to barrier impacts against these baseline results. The initial deformable barrier face was based on the mobile deformable barrier face used in FMVSS 214, which itself was based on impact research by NHTSA. Previous research had indicated that this was a reasonable representation of car-to-car impacts and that the principal effects were not too sensitive to the actual stiffness of the deformable element. Deformable barrier tests were performed at 40, 50 and 60 per cent overlap, 55, 60 and 65 km/h and with both the initial barrier face design and an alternative design with a second stiffer element behind the element used in the initial design. Additional tests with a further revised barrier face design, incorporating a wide bumper element ahead of the element used in the initial design, and tests at 50km/h were added following analysis of the results of the first phases of testing.

Working Group 11 proposed a new impact test procedure based on the result of 25 full scale impact tests performed in this EEVC-EC Research Programme and over 30 tests performed outside the EC Research programme by organisations collaborating in the EEVC work.

The main conclusions of the test programme, reported at the 14th ESV Conference[1], were that the test parameters which best replicated the baseline 50km/h 50 percent overlap car to car impact were as follows:

- the most appropriate design of deformable barrier consisted of a block of aluminium honeycomb of crush strength 50psi of depth 450mm with a smaller piece of 250psi honeycomb attached along the bottom edge of its front surface to act as a nominal 'bumper'. The barrier was mounted 200mm from the ground with its top surface at 850mm.
- the overlap which gave results most similar to a 50 percent, 50km/h car to car impact was 40 percent of the car's width.
- the test speed to replicate the 50km/h 50% overlap baseline test should be between 55km/h and 60km/h, but closer to the former. It was agreed that the most appropriate test speed to replicate the baseline tests was 56km/h.

However, the accident data showed that to address an adequate proportion of fatal and serious injuries, the test should replicate a car to car impact speed of 60km/h or greater. Initially, WG11 had included offset deformable barrier (ODB) tests at 65km/h. These tests had indicated that compliance with the test requirements might not initially be possible at such impact speeds. The recommendation of WG11 regarding speed was that it should initially be 56km/h but that it should rise to 60km/h or more once the manufacturers had become accustomed to the engineering involved in meeting the requirements.

Finally, EEVC recommended that, as the test procedure was based on a range of tests but using only three car models, the test procedure should be validated for a wider range of vehicle models.

VALIDATION PROGRAMME

An extensive programme was established to validate the test procedure. The five main aspects for evaluating the procedure were as follows.

Objectives.

Practicability This aspect examined whether there were physical problems in conducting the test according to the procedure or any shortcomings of the equipment needed which had not been shown up by the baseline programme. For example, where measurements were to be made, it was necessary to prove that they could be made accurately for all vehicle types. Similarly, the validation phase needed to ensure that problems did not exist with the deformable barrier face in tests with different vehicle categories.

Suitability of Performance Criteria For the first time in Europe, it was being proposed that injury criteria, measured on a dummy, should form the basis of a frontal impact test performance evaluation. Dummies have been used for many years in the United States and several of the injury parameters relating to the head and chest are well established. However, the procedure sought to encompass serious injuries to other body areas, most notably the lower legs, as accident studies are now demonstrating the importance of these injuries. Such injuries are disabling, expensive to treat and can have long-term effects. Less experience was available in Europe for the dummy injury criteria relating to these parts of the body compared with the upper body. To account for injuries in areas not encompassed by a single test using a single dummy size, EEVC proposed a limit on steering-wheel displacements and easy removal of the dummy after the test. The validation programme examined each of the proposed parameters in terms of the following.

a) that the parameter should be easily measurable using widely available equipment
b) that measurements of the parameter should be repeatable between nominally identical tests and
c) that the parameter should relate to some aspect of the car's behaviour.

Test Speed None of the three cars tested in the earlier programme had performed well at test speeds of 60km/h or greater and this had led to the proposal for a phased increase in the test speed. This would enable cars to meet the requirements at the introduction of the test whilst also covering a significant proportion of serious and fatal injuries in the longer term. The validation phase examined the performance of more recently designed vehicles. To evaluate whether the earlier concerns were valid also for more modern designs, tests were carried out both at 56km/h and 60km/h.

Repeatability The validation programme sought to establish the repeatability of tests using the offset deformable barrier. Three identical cars were tested at the same establishment and the results compared.

Reproducibility The validation programme examined the reproducibility of the test procedures by comparing the results of nominally identical tests conducted on the same model of car by different test-facilities.

Validation Tests

Table 1.
Validation Test Programme

		56 km/h	60 km/h
	Car Model code	Number of tests	
Repeatability	C	3 (C1,2,3)	
Reproducibility	C	2 (C4, 5) [C2]	
Small car	A	1 (A1)	1 (A2)
Small car	B	1(B1)	
Small car	L	1(L1)	
Medium car	C	1 (C7)	1 (C6)
Medium car	D	1(D1)	
Family car	E	1 (E1)	1 (E2)
Family car	F	1 (F1)	
Large car	G	1 (G1)	1 (G2)
People carrier	I	1 (I1)	
Off road	J	1 (J1)	
Minibus	K	1 (K1)	

Table 2.
Vehicle Models Tested

Model code	Description	Model Year	Airbag
A	Small Hatchback	1989	✓
B	Small Hatchback	1993	✗
C	Family Hatchback	1992	✓
D	Family Hatchback	1988	✗
E	Large Family Hatchback	1993	✓
F	Large Family Hatchback	1993	✗
G	Large Executive Saloon	1994	✓
I	Multi Purpose Vehicle	1990	✓
J	Off-Road Vehicle	1995	✗
K	Minibus	1992	✗
L	Small Hatchback	1986	✗

Table 1 shows the test performed within the Validation Programme and Table 2 describes the characteristics of the vehicles used.

<u>Barrier Face Design</u>. At the end of the first phase of the WG11 programme, the agreed barrier design consisted of a main block honeycomb with a smaller piece of stiffer material attached to the front lower edge of this block to act as a nominal 'bumper' section. Before testing for the validation phase had begun, a problem experienced using this barrier design was reported to the Working Group which was seen to be due to the stiff longitudinal member of the car aligning with the upper part of the bumper section and the impact rotating the bumper horizontally rearward into the main honeycomb block with little or no bumper deformation. This caused the barrier face to be pushed downwards and the vehicle to be pushed upwards, overriding the bumper section. With the main honeycomb block dragged downwards, its stiffness in the impact direction was greatly reduced.

This phenomenon was replicated and overcome using a trolley with a simulated rigid bumper impacting the standard barrier design and modifications to it. It was found that, by introducing two horizontal slots across the whole width of the bumper splitting it into three equal parts, rotation of the whole bumper section was avoided. This revision to the deformable face was incorporated into the barrier design and was used throughout the Validation phase.

For the development phase, where different overlap extents were used, the width of the barrier was 1500mm. It was found that, in all tests, a large proportion of the barrier was undeformed after the impact and had effectively played no part in the test. The minimum width necessary to allow testing of 40 percent of the widest vehicles currently in production was calculated and it was decided to reduce the width of the barrier to 1000mm. in the Validation Programme

RESULTS

The results of the test programme are presented in Figures 1 - 19.

Practicability.

<u>Barrier Face</u> During the validation phase tests, it was found that some tall vehicles (J, K) impacted the rigid concrete block above the deformable face. This contact was not representative of an impact with a conventional car. To eliminate such effects, the barrier specification has been changed to include the requirement that no part of the vehicle should impact any structure at a height more than 75mm above the upper surface of the deformable face in the test. The 75mm was simply to allow for the mounting flange on the barrier. This would require the deformable face to be mounted away from the rigid block for some tests.

For the other aspects, the barrier face as then specified was found to perform satisfactorily. In some cases, some stiff members penetrated the deformable element. This was generally not considered to be of major importance because one of the main advantages of a deformable face is the removal of the initial very high inertial force generated when the stiffer members of the car structure impact a rigid wall. The deformable face achieves this very successfully. With the modifications proposed, the barrier face design is considered to be satisfactory and the only validated design available for offset frontal impact testing. Tests by several institutes reported to WG11 show that the effect of further changes to the barrier design will be small in comparison to this change. Nevertheless, it is expected that research on the barrier face design will continue and the design may be revised to take into account future research findings on the requirements for improved compatibility.

Dummy Removal WG11 proposed that, after the test, the dummy should be capable of being removed without the use of tools and without adjusting the seat position. Furthermore, the dummy should not be broken and should still be within calibration and suitable for use in other tests.

It was found that the ease of dummy removal was subjective in the same way as the door-opening requirements i.e. it depended largely on the person involved. Moreover, in some countries, Health and Safety regulations limit the weight that an individual should be required to lift in the workplace. Nevertheless, it is recommended that this requirement for the dummy removal be retained, predominantly as a method of limiting intrusion at the facia and footwell levels. The use of equipment to support the weight of the dummy should be permitted.

The experience among the test laboratories participating in the discussions is that a dummy can sustain damage during a test which is undetectable in a visual examination but the dummy can still meet the performance corridors of its calibration requirements. Thus any obvious damage to the dummy in a test could have been precipitated by damage in previous tests and therefore cannot be an independent assessment of the severity of impact to the dummy in that test. For this reason it is recommended that the requirement for the dummy to be undamaged and fit for further use should be withdrawn.

Performance Criteria.

Head Injury Criteria. The Head Injury Criterion (HIC) is well established an no problems were experienced in recording and calculating this parameter. The 36ms value was selected in conformity with that specified for use in FMVSS208, although unlimited and 15ms values were recorded also. There was no case of a vehicle exceeding 1000 for HIC or HIC_{36} but meeting 700 or 1000 for HIC_{15}.

A presentation from Transport Canada to the working Group for a requirement for the peak resultant head acceleration not to exceed 80g was considered. The basis for this is that this limit has been found to give a reliable indication of rigid or hard impact by the head. All road accident studies indicate that head injury in the absence of hard head contact is almost unknown. It was felt that this did provide a useful additional protection criterion, but concern for spurious spikes in dummy instrumentation led to the introduction of a 3ms exceedence for this criterion. One vehicle exceeded this limit without exceeding 1000 for HIC_{36}. This vehicle was not equipped with an airbag.

Neck. Five neck injury criteria were included in the original proposals: Flexion and extension moments (peak values) and axial tension, compression and shear (time - duration limits). EEVC were asked to consider whether five parameters were necessary. The neck is a very complex structure which can fail through a number of mechanisms in vehicle accidents. However, it was recognised that, in a regulatory test it would be necessary to limit the requirements to those that are most likely to be relevant to the frontal impact situation. While EEVC WG11 feel that all five parameters are appropriate for scientific research, the recommended neck injury performance criteria for use in a regulatory test procedure are reduced to neck tension, neck shear and neck extension , considered to be most relevant to frontal impact testing with restrained occupants after consultations with SAE biomechanics experts.

All parameters were straightforward to record and compliance with the duration-exceedence limits proved to be simple to determine. The Working Group would like to see further research in the area of neck injury biomechanics to improve the confidence in the injury criteria. Nevertheless, these three parameter are considered to be the best available and to be suitable parameters for use in the test procedure.

Chest. Chest compression limits of 50mm and a Viscous Criterion value of 1m/s had been proposed. No problems were experienced in measuring and calculating these parameters. No vehicle exceeded either criterion in any test within the Validation Programme. It is recommended that they continue to be specified for use in the test procedure.

Abdomen. No requirement for the abdomen was specified in the original proposal as no suitable criterion could be found for use with the Hybrid III dummy. WG11 agrees that the compression and probably the rates of compression of the abdomen should be limited, but currently cannot recommend a satisfactory procedure for use in a regulatory test. It is recommended that this aspect of dummy design and instrumentation be addressed as soon as possible.

Femur. A force-duration exceedence curve was proposed. As with the neck force-time criteria, this was found to be easy and practical to measure and to determine compliance. no vehicle exceeded the criterion in any test in the Validation Programme. It is proposed to retain this criterion.

Knee Joint Translation. During the Validation programme, problems of binding were experienced with the original knee slider joints. Characteristic slip-stick responses were observed from the transducers. This will lead to an underestimate of the injury risk to the knee ligaments. This would be of greater concern if the results were likely to give an over estimate of the response. A replacement knee joint, using a roller bearing design, is now available and appears to have resolved this problem. Although this parameter was introduced to provide an assessment of the performance of knee bolsters used in US cars in association with airbags, it is considered to be a useful additional protection requirement for use with European cars to avoid potentially dangerous loading to this body area. It is proposed to retain this criterion used in association with the roller ball design of knee joint.

Tibia. Two criteria were proposed for use with the Hybrid-III dummy for tibia injury protection with the expectation that additionally there would be some measure of protection for the ankle joint: the peak axial compression and the tibia index..

The peak compressive force, set at 8kN based on the tolerance of the tibial condyles, was not exceeded in any test.

The performance limit for the tibia index was proposed to be 1.0. The validation programme tests demonstrated that this parameter was variable. It is not clear at present whether this is an innate feature of the parameter or whether vehicles do not perform consistently in this area, which is not currently the subject of a performance requirement. The variation of this parameter in the repeatability tests was examined and allowance for this was made in the revised proposed limit of 1.3

A problem with the foot design of the Hybrid III dummy became apparent during the evaluation of the Tibia Index results. Although the revised ankle design intended to give 45° dorsiflexion was specified and used in the Validation programme, this retained the metal to metal end stop to the articulation. This was demonstrated to give spikes in the transducer signals on occasions, leading to variation in the test results and artificially high readings. A revised foot and ankle has been designed by First Technology, in association with SAE, NHTSA and EEVC to resolve this problem. It is important that this foot and ankle be used when the tibia responses are required. WG11 have developed a certification procedure for this foot and tibia.

With the use of the new 45° foot and ankle with damped end stops, it is recommended that the tibia compressive force and the tibia index be used, with a critical value of 1.3 for the tibia index.

EEVC Working Group 12 will be evaluating new designs of leg for use with the Hybrid III dummy. If one of these proves to be significantly better than the existing leg in terms of biofidelity and injury detection, WG11 would like to see this new leg incorporated into the test procedure.

Steering Wheel Displacement. The original proposal included a limit on the rearward and upward displacement of the steering wheel hub centre and the upwards rotation of the steering column. The test programme demonstrated that, particularly with cars fitted with driver side airbags, the measurement of the displacement of the steering wheel hub was not practical. This was changed during the programme to the displacement of the top of the steering column. By removal of the steering wheel, this measurement proved to be easy and practicable. Examples were observed of gross steering wheel motion into the face or neck of the dummy but without exceeding the performance criteria, demonstrating the need for this additional requirement, especially as a single size dummy only is proposed for Europe.

It was originally considered that a limitation on the angular displacement of the steering column would provide an additional safety evaluation independent of the linear displacements. This measurement proved difficult to measure reliably in the Validation Programme and did not appear to provide any additional information. Therefore it is proposed to retain only the rearward and vertical displacement of the end of the steering column.

Footwell Intrusion. During the test programme, some concern was expressed at the large and high speed displacement of the brake pedal. As the dummy foot is placed on the accelerator (in harmony with FMVSS208), this would not be detected by dummy readings. A criterion based on brake pedal residual displacement was considered but it was felt that the correlation with injury mechanisms and risk was too tenuous for this to be included in the final proposals. No footwell intrusion requirements are proposed.

Dummy Condition An additional requirement proposed was that the dummies should be capable of being removed without tools and that they should not be broken in the test and should still be within calibration and suitable for use in other tests. The former requirement has been discussed above.

Since a dummy can sustain damage during one test which is undetectable in a visual examination and the dummy can still meet the performance corridors of its calibration requirements in preparation for the subsequent test, it is not an appropriate condition for use as an approval criterion. Therefore it is recommended that the requirement for the dummy to be undamaged and fit for further use should be withdrawn.

Table 3
Proportion of Models Tested Meeting the Proposed Performance Criteria

Performance Criterion	56km/h		60km/h	
	No within limit	Models not in limit	No. within limit	Models not in limit
HIC (36)	10/11	J	4/4	
Head 3ms g	9/11	J B	4/4	
Neck Tension.	8/10	J B	4/4	
Neck Shear	11/11		4/4	
Neck extension.	11/11		4/4	
Chest comp.	10/10		4/4	
V*C	10/10		4/4	
Femur Force	11/11		4/4	
Knee slide	11/11		4/4	
TI (1.3)	11/11		1/4	C E G
TI (1.0)	8/11	E J L	1/4	C E G
Tibia Compress Forc	11/11		4/4	
All dummy criteria (	[illegible]	J B	1/4	C E G
[All dummy criteria (TI 1.0)	7/11	B E L J	1/4	C E G]
Steering col; Vertical	8/11	B G I	3/4	G
Steering Col, Horizontal	8/11	D J L	3/4	A
All geometric	5/11	B D G I J L	2/4	A G
ALL Crit (TI 1.3)	4/10	B D G I J L	0/4	A C E G

__Test Speed__. The first eight figures show the results for 11 different vehicles tested at 56km/h for HIC, Head Acceleration (3 ms exceedence), Neck extension moment, Chest compression, V*C, Peak femur force, Peak tibia compressive force and Tibia Index. All of the vehicles met the proposed dummy performance criteria requirements except for the Off-road vehicle, which exceeded the HIC limit, the head acceleration (3ms) limit and the neck tension limit and one small car (without airbag), which exceeded the head acceleration (3ms) limit and the neck tension limit. One small car, the off-road vehicle and one of the family cars (just) would have failed the Tibia Index Limit at the original value of 1.0. In all these cases, the kinematics and loading of the dummy, judged from examination of the high speed film and post impact vehicle condition, gave support to the high values for these parameters.

The following six figures (Figures 9, 10, 11, 12, 13 and 14) give a comparison between the results for the four models of car tested at 56km/h and 60km/h. HIC, Head

Acceleration, Chest compression, Femur force and Tibia Index and steering wheel displacement are shown as examples. It can be seen that the effects of testing at the higher speed on the injury parameters are relatively small, keeping them within the proposed limits, except for the Tibia Index. Testing at the higher speed has increased the displacement of at least one dimension of the steering wheel. For these four models at least, testing at 60km/h does not appear to be as severe as the test results from the first test series, although attention would need to be paid to the footwell area and to steering wheel displacement at the higher speed.

The performances of the vehicles tested in the validation programme were significantly better than those of the older car models tested in the development programme. In the impact test development programme, the performance of the cars was such that compliance at 60km/h or higher was not thought possible. Table 3 shows the number of vehicle models meeting the proposed criteria at 56km/h and 60km/h..

At 56km/h, 8 of 10 vehicle models were within all of the dummy-based criteria while at 60km/h all four vehicle models (all equipped with driver side airbags) met the proposed dummy based criteria with the exception of the tibia index. It is , perhaps, not surprising that the tibia index criterion should be exceeded since this area of the vehicle's performance is not currently subject to any legislative test requirements and this test procedure reproduces the conditions leading to tibia injury more accurately than the current perpendicular rigid wall test.

The proposed limits on steering wheel displacement were met by 5 of 11 cars at 56km/h although the individual requirements were met by 8 of the 11. For the four models tested both at 56km/h and at 60km/h, three of these were within the proposed limits at 56km/h, but only two were at 60km/h.

Bearing in mind the superior performance of these modern vehicles in comparison with those older designs tested in the development programme, a move to the higher impact speed indicated by the accident studies should be reconsidered in the future. EEVC Working Group 11 recommends that a test programme designed to compare barrier impacts to higher speed car-to-car impacts be performed to form a basis for a future test at an increased impact speed. Due regard should be taken of the implications for overall injury rate.

Repeatability and Reproducibility. Figures 15 ,16, 17, 18, 19 and 20 give an indication of repeatability and reproducibility. Six dummy responses are shown here for illustration. The first three bars show the results for the "medium" passenger car number 1, all tested at BASt. The results for these three repeat tests indicate good repeatability for these cars, especially for the upper body parameters. The variation of the leg parameters (Femur Force and Tibia Index) is more, as might be expected for this body region. It should be remembered that the Tibia Index for each dummy is the maximum value of the tibia index expression, irrespective of location and this may not be the same in each case.

The curves in figure 21 are the time histories of the head accelerations, chest accelerations and chest compressions seen in the three repeatability tests performed at BASt. The closeness of these lines indicates the good repeatability seen in these tests.

The fourth and fifth bars in figures 15 - 20 give the results for the same model of car tested at Fiat and TNO. They indicate the reproducibility of the test - or the variations found when the same vehicle model is tested at different establishments. Here again, the variations seen are considered acceptable, with the exception of the higher result for the Tibia Index seen in the test at Fiat. The reason for this odd result is not understood; the result at TNO being in good agreement with the results at BASt.

SUMMARY OF TEST PROCEDURE AND REQUIREMENTS

Impact Test Procedure.

The impact test should be an offset frontal impact into a fixed deformable barrier.

Barrier: The barrier should be a fixed barrier with a deformable face. The front face of the deformable element should be perpendicular to the direction of travel of the target vehicle. The design of the barrier face is given in Appendix A. The barrier face should be attached to the fixed block such that no part of the block or mounting surface greater than 75mm above the top surface of the deformable barrier face can contact the vehicle during the test.

Offset: The offset of the impact is defined by the percentage overlap on the vehicle front. The vehicle should impact the deformable face such that the barrier face overlaps the driver's side of the front of the car by 40 percent (± 50mm.) of the external width of the car at the widest point (excluding wheel trims and mirrors etc).

Dummies: The test should be performed with one 50th percentile Hybrid III dummy in driver's seating position and one 50th percentile Hybrid III in outer front seat passenger's seating position. The dummies should be equipped with the 45° 'damped end stop' ankle and subject to the foot and tibia certification tests. Each dummy should be clothed in standard clothing and should wear shoes. The specifications for the use of these dummies should follow FMVSS208. Fiftieth percentile adult dummies shall be placed in each of the other seating positions (except the centre front) unless these are fitted with 3-point seat belts to ECE Reg 16 or EC Directive 77/541.

Vehicle Condition: All seat and steering wheel adjustments should follow the FMVSS208 practice. Additional to the FMVSS specification, the dummy torso should be tilted forward and back twice after the seat belt has been attached to ensure a more realistic lie of the seat belt across the torso.

Impact Speed: The speed of the vehicle immediately before impact with the deformable barrier should be 56km/h. with a tolerance range of 2 km/h.

Performance Requirements.

Dummy Response Requirements.

Head. (i) The HIC_{36} shall not exceed 1000.
(ii) The resultant head acceleration shall not exceed 80g for more than 3 milliseconds calculated cumulatively. (This should not be applied to impacts which occur during the rebound phase)

Neck. (i) The neck tension and neck shear shall not exceed the criteria-duration limits given in figures B1 and B2 respectively (Appendix B).
(ii) The neck extension shall not exceed 57Nm.

WG11 recommends that neck flexion moment should be recorded in the test for future reference without applying a performance limit.

Chest. (i) The chest compression shall not exceed 50mm.
(ii) The Viscous Criterion shall not exceed 1.0m/s.

Femur. The femur force should not exceed the force-time performance criterion given in figure B3 (App. B)

Knee. The movement of the sliding knee joints shall not exceed 15mm.

Tibia. (i) The axial compression of the tibia should not exceed 8kN
(ii) Tibia Index ($TI = Mr/M_c + Fz/F_c$) should not exceed 1.3

where Mr is to be taken as a resultant of Mx and My, M_c (critical bending moment) = 225Nm and F_c (critical compressive force) = 35.9kN.

The expression for TI should be calculated both at the top and the bottom of each tibia as a continuous time function. The Tibia Index is taken as the maximum value recorded during the time histories, irrespective of location.

Vehicle Response Requirements.

Steering Column. The residual displacement of the centre of the top of the steering column shall not exceed 80mm in the vertical direction nor 100mm in the rearward horizontal direction.

Dummy Extraction The dummy must be capable of being removed after impact without tools (except for equipment to support the weight of the dummy during removal) and without adjustment of the seat position.

Future Aspects.

The impact speed and many other aspects should be reviewed after a few years' experience has been gained in applying this test procedure.

Supplementary Requirements.

Although not necessarily an integral part of this test, it would appear to be appropriate to include requirements for fuel system integrity to avoid unnecessary duplication of standards and tests. It is recommended that consideration be given to the integrity of the firewall when reviewing the fuel system integrity test. In addition, there should be a requirement that the battery should not be ejected from the vehicle during the impact to avoid danger to other road users in a crash. Manufacturers should provide a mechanism for ensuring that fuel pumps are switched off at impact or when the engine stops. The battery may be dry during the test.

Additional Testing.

The full scale test evaluates a number of very important aspects of the injury risk to the vehicle occupants in a frontal impact. There are a number of aspects that cannot be assessed in this single test and which the EEVC WG11 feels need to be addressed.

Steering wheel impacts. Even if head or face to steering wheel contact does occur in the full scale test, the single test will evaluate only one single point impact of the wheel. In addition, the injury parameter measured on conventional dummies relates to brain injury rather than the facial skeleton injury that is common in face to steering wheel impacts. Accident studies clearly indicate a wide range of actual contact locations on the steering wheel. EEVC WG11 strongly advocates the use of an additional supplementary test to evaluate the facial and brain injury from steering wheel impact.

Seat and seat attachment. The strength of the seats and seat attachment cannot be fully addressed in this test. In particular, the effect on the dynamic performance of the seat, if it is possible to leave the adjuster out of engagement or partially engaged, needs to be considered by design requirements or a separate dynamic test. This can be even more important where one or both seat belt lower anchorages are attached to the front seats. The ability of the rear seat backs to withstand the impact forces of luggage was considered for incorporation in the full scale test, but it was decided that it would be simpler to evaluate this also in a separate test.

Seat belts and anchorages. Similar considerations led to the decision that the dynamic performance of an adjustable upper anchorage that could be left in an intermediate position would be better dealt with elsewhere. It was considered that it would be desirable to maintain a component test of the seat belt to enable simple and inexpensive routine testing for production conformity to take place. This would be necessary also for such aspects as durability and wear. The need for a requirement on anchorage strength would remain as the proposed test procedure would only assess anchorage strength up to the 50th percentile person at this impact severity.

APPENDIX A

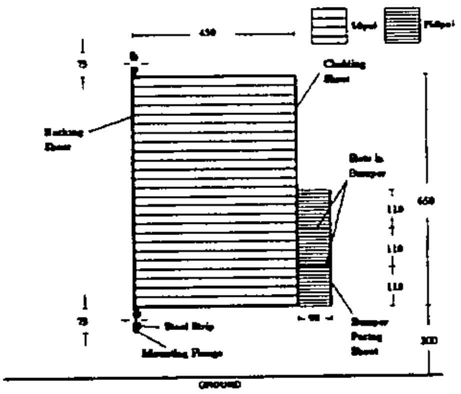


Figure A1 Deformable Barrier Design.

APPENDIX B

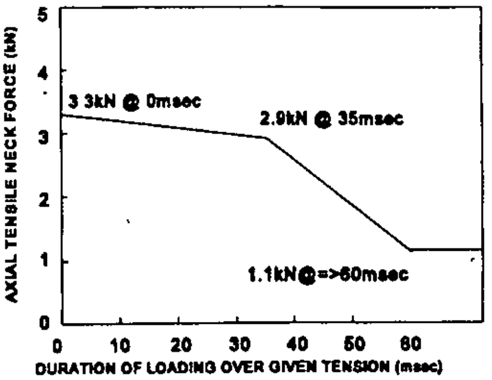


Figure B1. Neck Tensile Performance Limit

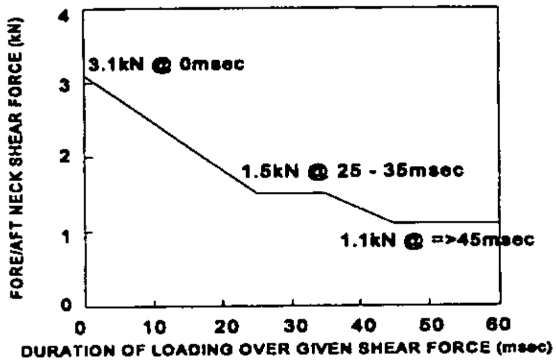


Figure B2. Neck Shear Performance Limit

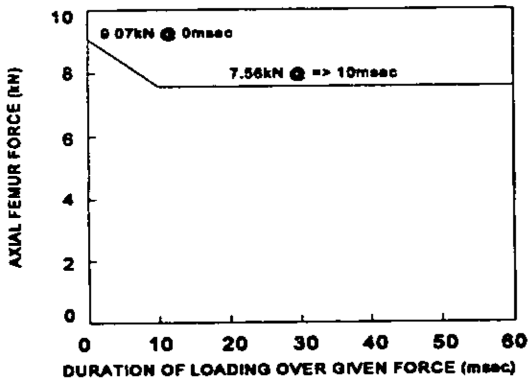


Figure B3. Femur Force Performance Limit

EEVC Working Group 11 Members

R W Lowne	TRL	UK	(Chairman)
C A Hobbs	TRL	UK	(Secretary)
P-L Ardoino	MoT/Fiat	Italy	
D Bigi	MoT/Fiat	Italy	
J P Bloch	INRETS	France	
D Cesari	INRETS	France	
E Faerber	BASt	Germany	
J Huibers	TNO	Netherlands	
J J Nieboer	TNO	Netherlands	
C Nilsson	MoT/Saab	Sweden	

Observers

K Ando	JETRO	Japan
F Bendjellal	APR	France
P Bodin	Renault	France
D Dalmotas	Transport Canada	Canada
A Engerer	AAMA	USA
E Fossat	Fiat	Italy
J Green	Rover	UK
R J Hitchcock	NHTSA	USA
Y Heishi	Nissan	Japan
M Iwasaki	Toyota	Japan
M Kitano	Nissan	Japan
Y Lambert	PSA	France
D Lehman	VW	Germany
A Lund	IIHS	USA
B Lundell	Volvo	Sweden
P Massaia	Fiat	Italy
K Matsumoto	MoT	Japan
M Miyakawa	JASIC	Japan
R Nagel	AAMA	USA
H Neff	Ford	Germany
R Nilsson	Volvo	Sweden
K Oki	JASIC	Japan
B O'Neill	IIHS	USA
K Seyer	Fed. Off. Road Safety	Australia
I Skogsmo	Volvo	Sweden
P V Skuse	Rover	UK
C Steyer	Renault	France
T Takahashi	MoT	Japan
O Takatory	JARI	Japan
C Thomas	APR	France
H M Thum	ACEA	Europe
I Tokunaga	JASIC	Japan
E R Welbourne	Transport Canada	Canada
S Yamaguchi	JASIC	Japan
T Yamanoi	JASIC	Japan
E Heyne	Opel	Germany

Special presentations have been made by:-

T Hollowell	NHTSA	USA
H Norin	Volvo	Sweden
D Otte	Hannover Med. School	Germany
C Tarrière	Renault	FranceP
Thomas	ICE	UK
C Tingvall	Folksam	Sweden
U Westfal	ACEA	Europe
F Zeidler	Mercedes-Benz	Germany

REFERENCES

1.EEVC. EEVC Working Group 11 Report on the Development of a Frontal Impact Test Procedure. Proc. 14th Conference on the Enhanced Safety of Vehicles, Munich, May 1994. paper 94-S8-O-05.

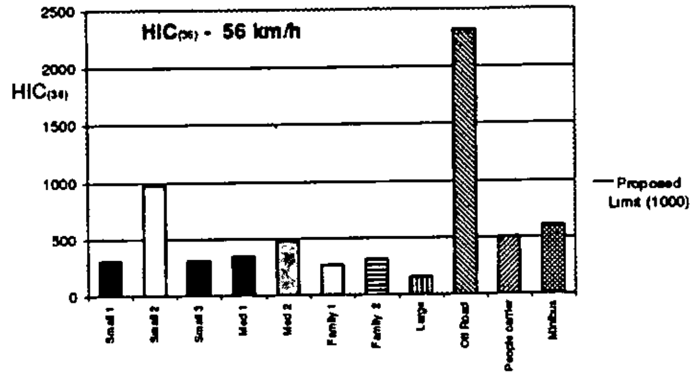


Figure 1. HIC_{36} measured in tests at 56km/h

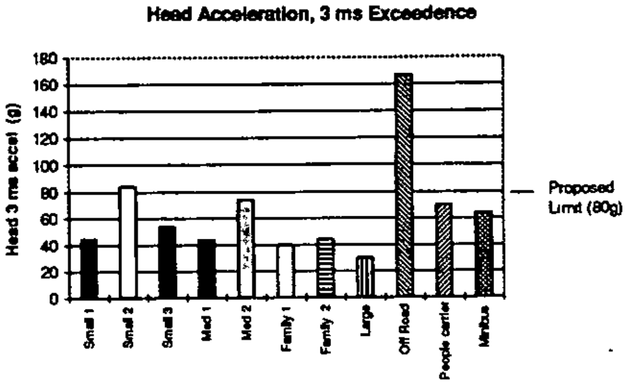


Figure 2. Head acceleration 3ms exceedence in tests at 56km/h.

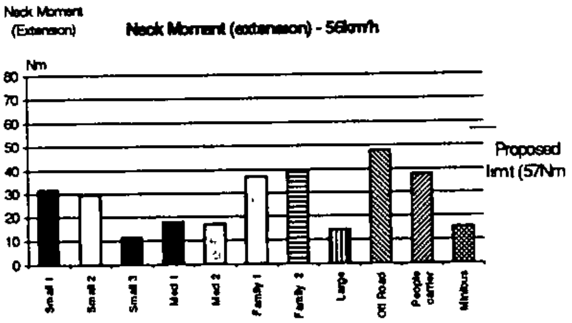
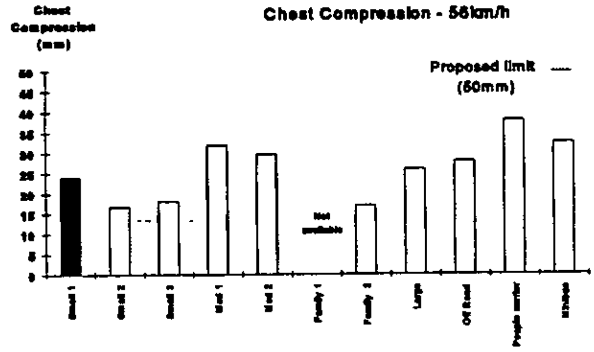


Figure 3. Neck extension moment in tests at 56km/h



.Figure 4. Peak chest compression in tests at 56km/h

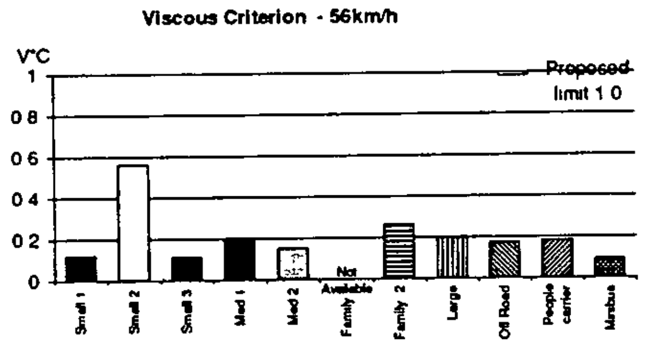


Figure 5. Viscous criterion (V*C) in tests at 56km/h

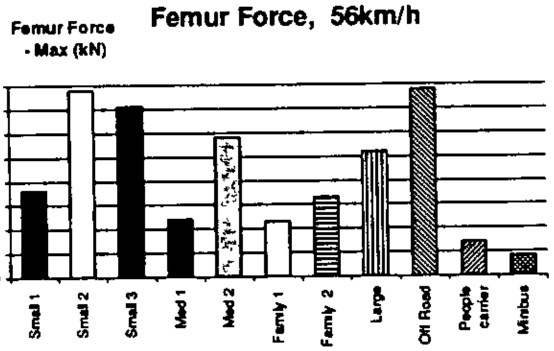


Figure 6. Peak femur force in tests at 56km/h.

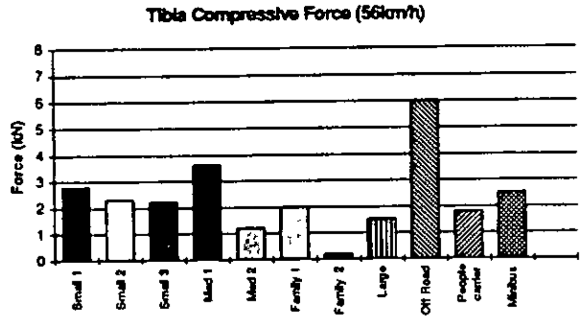


Figure 7. Tibia compressive force in tests at 56km/h.

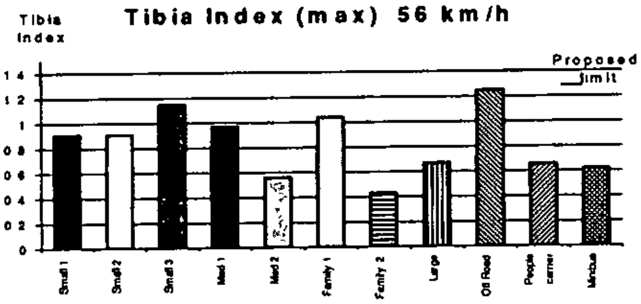


Figure 8. Tibia index in tests at 56km/h.

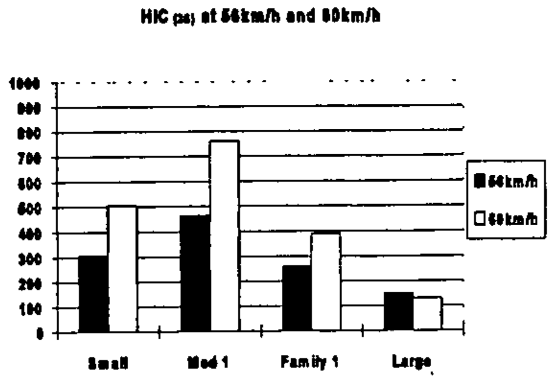


Figure 9. HIC_{36} measured at 56km/h and 60km/h

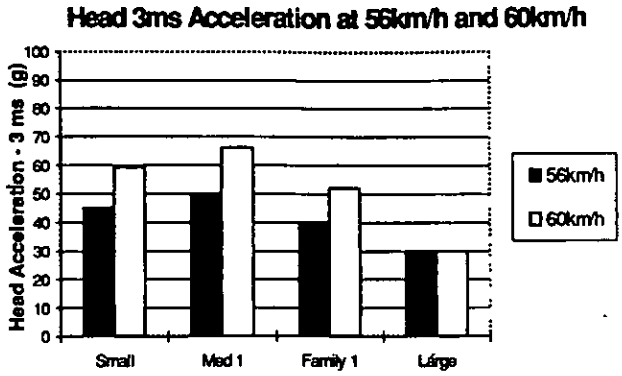


Figure 10. Head acceleration (3ms) measured at 56km/h and 60km/h

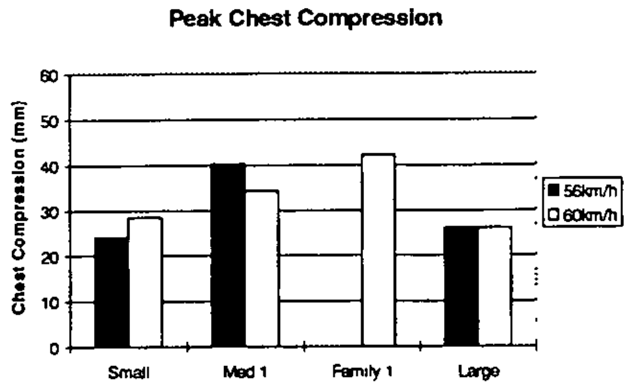


Figure 11. Peak chest compression measured at 56km/h and 60km/h

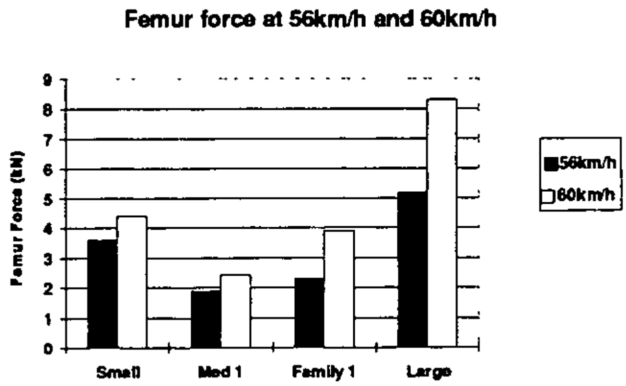


Figure 11.Peak femur force measured at 56km/h and 60km/h.

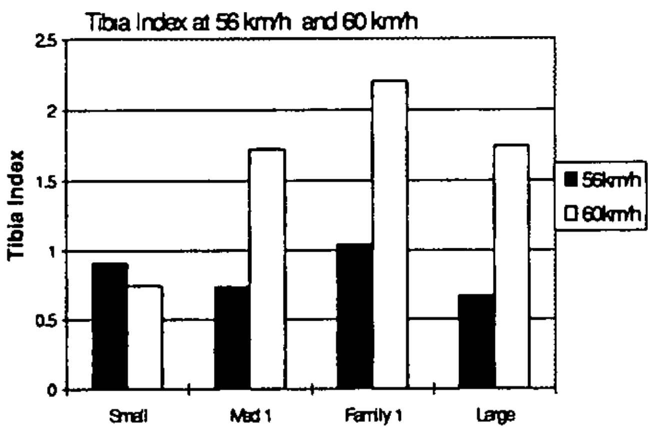


Figure 13. Tibia Index measured at 56km/h and 60km/h

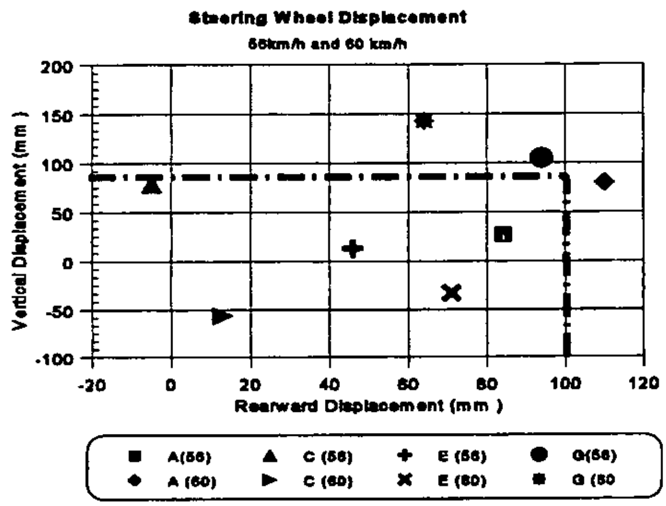


Figure 13. Vertical and horizontal steering wheel residual displacement measured at 56km/h and 60km/h

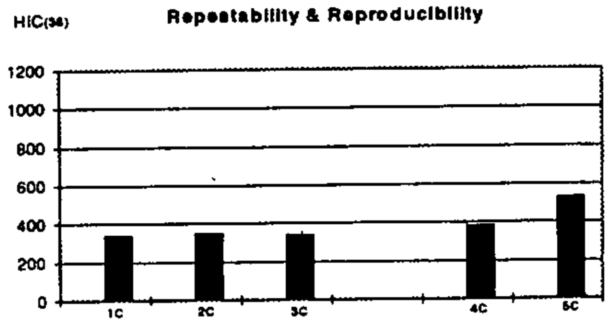


Figure 16. Repeatability and reproducibility of HIC_{36}

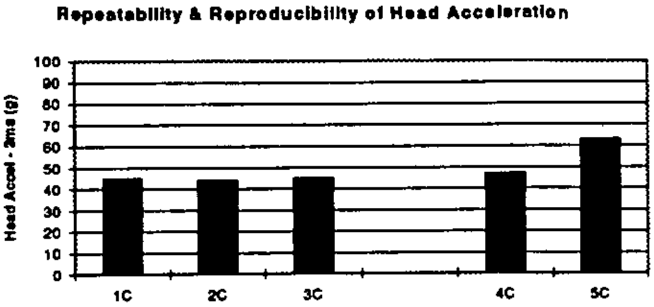


Figure 15. Repeatability and reproducibility of head acceleration.

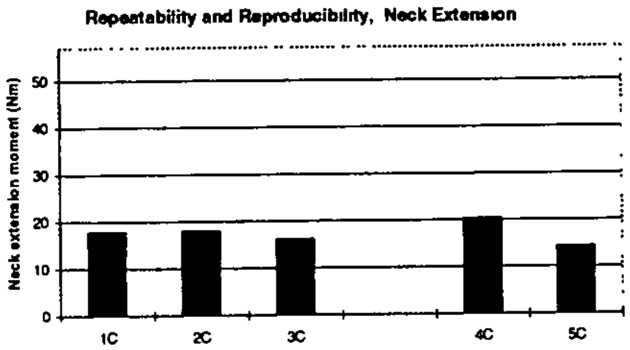


Figure 17 Repeatability and reproducibility of neck extension moment

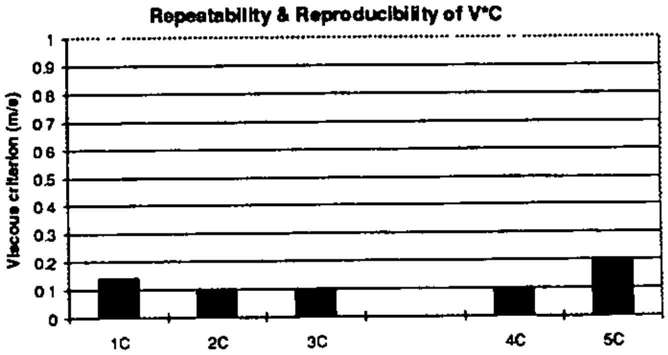


Figure 18 Repeatability and reproducibility of the viscous criterion

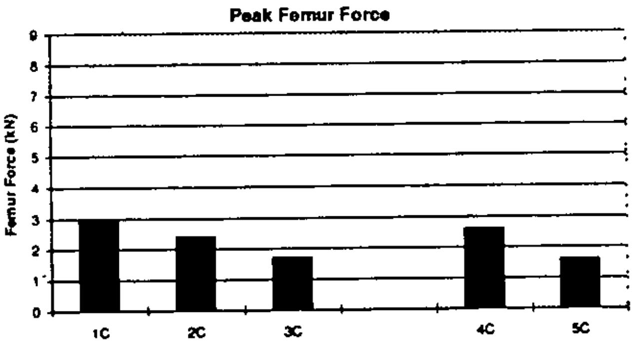


Figure 19. Repeatability and reproducibility of the femur force

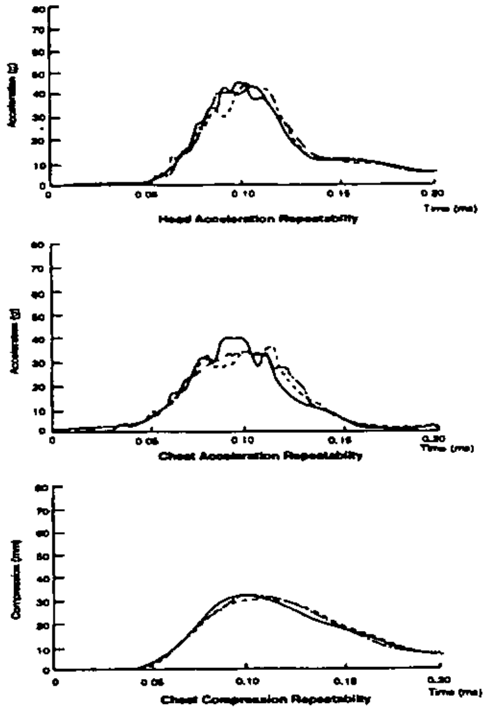


Figure 20 Repeatability of head acceleration, chest acceleration and chest compression, vehicles 1C, 2C and 3C.

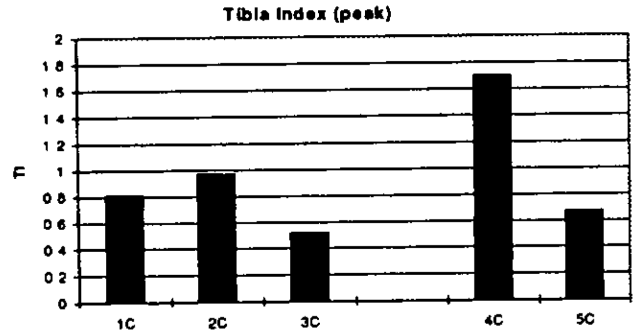


Figure 21. Repeatability and reproducibility of the tibia index.