DEVELOPMENT OF THE EUROPEAN NEW CAR ASSESSMENT PROGRAMME (EURO NCAP)

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ABSTRACT

For the first time in Europe, comprehensive consumer information on the crash performance of cars has been made available to the public, through the European New Car Assessment Programme (Euro NCAP). Cars have been tested in full scale offset frontal and side impacts and the aggressivity of the car front to pedestrians has been assessed. The test procedures used are based on those developed, by the European Enhanced Vehicle-safety Committee, for legislation in Europe. In order to show how well the car and the recommended child restraints work together, restrained child dummies were seated in the rear of the car, in both the frontal and side impact tests.

An assessment protocol has been developed to provide an objective evaluation of the protection provided by the cars. The assessment protocol uses occupant trajectory, vehicle deformation and inspection data, in addition to the dummy instrumentation data, to provide an evaluation of the protection provided by the car for a range of occupant sizes. This paper outlines the objectives of Euro NCAP and gives details of the test and assessment procedures used. Test results for the completed phases are presented along with the ratings for occupant and pedestrian protection.

INTRODUCTION

Consumer information crash test programmes have proved effective in improving car safety in a number of countries. The European New Car Assessment Programme (Euro NCAP) was developed in the United Kingdom with the aim of bringing about such improvements throughout the European Union. Euro NCAP has grown with sponsorship from other European countries, the European Commission, European consumer groups and international motoring organisations. Euro NCAP carries out frontal, side and pedestrian impact tests and includes an assessment of how well the car and the manufacturer's recommended child restraints protect young children. After initial hostility, most manufacturers have become more positive about Euro NCAP and the industry is now contributing to the development of the programme. More importantly, many manufacturers are responding rapidly by improving their cars and by standardising safety features throughout the European Union. The rate of improvement in occupant protection is such that reductions in car occupant casualties should soon be identifiable in accident statistics. Improvements for the pedestrian are developing more slowly but there is a clear indication that manufacturers are at last taking the protection of pedestrians seriously.

A summary of the results of the first two phases of Euro NCAP tests is given in Appendix I.

EURO NCAP AIMS

Legislative safety standards set a minimum level, below which no car's performance is allowed to fall. However, they provide no incentive to encourage manufacturers to provide higher standards of safety. Manufacturers do respond to consumer demands and, for many years, consumers have been provided with a wealth of information to help them make their choice. Absent from this information has been comprehensive data about the crash performance of cars. Euro NCAP is now starting to provide this information which, in combination with other data, can be used by consumers to help in their car choice. The use by consumers, of crash safety information, provides a strong incentive to manufacturers to improve the safety of their products. Those manufacturers who choose to excel at crash protection, obtain recognition for their efforts and this can result in increased market share.

EURO NCAP INFRASTRUCTURE

Euro NCAP is sponsored by: the European Commission, the governments of the Netherlands, Sweden and the United Kingdom; motoring organisations, through the Alliance International de Tourisme (AIT) and Federation International de l' Automobile (FIA); the German motor club Allgemeiner Deutscher Automobile Club (ADAC) and European consumer groups, through International Testing. Further sponsors are expected to join in the future.

Policy is determined by a Steering Committee, acting through a Secretariat. Technical aspects are dealt with by a Technical Working Group, which is also responsible for rating the cars. Protocols have been developed which detail the testing (1) and assessment procedures (2).

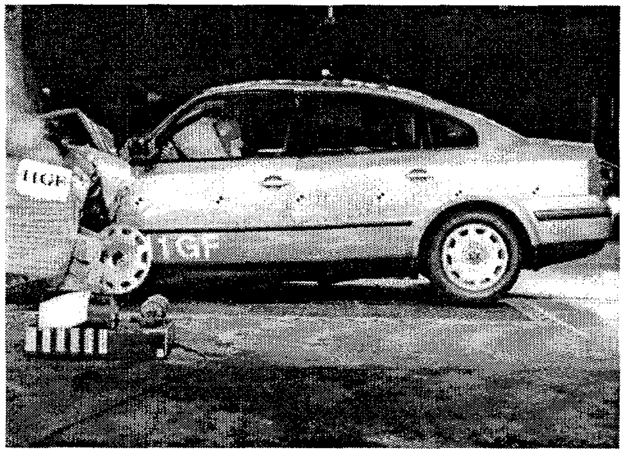

Figure 1. Euro NCAP Offset Deformable Barrier Test at 64 km/h.

Currently, two laboratories carry out the testing: TNO, in the Netherlands and TRL, in the United Kingdom. Vehicle inspections are carried out by Vehicle Safety Consultants. As Euro NCAP grows, it is expected that additional organisations will be approved to carry out the testing and inspection tasks.

CAR SELECTION AND PURCHASE

As the frontal impact test is designed to simulate a car to car impact between two similar cars, car size is not accounted for. Euro NCAP tests and compares cars within size categories. No attempt is made to compare the performance of cars from different size categories. In frontal impacts between heavy and light cars, it is clear that momentum effects favour the occupants of the heavy car. Other characteristics also tend to favour larger cars. However, in impacts with substantial roadside obstacles, the advantages of being in a heavier car are less clear. In side impacts mass has a more limited effect, whereas size, in particular seat height, has a greater effect. In this test, the impact simulates the car being hit by a fixed size of "bullet" car.

Once a size category is chosen for testing, the sponsors choose which cars to include in the programme. With most car models, there are a variety of body style, engine, transmission and safety related options available. Euro NCAP aims to test the variant with the largest sales within the European Union. It is recognised that differences within a model range have some effect on crashworthiness, just as it is recognised that there are differences in the performance of right and left hand drive cars. Euro NCAP can take no account of this. It is a manufacturer's responsibility to ensure that a car's performance is not unduly compromised by such factors.

From the third phase, Euro NCAP will only test cars with safety equipment fitted as standard throughout all fifteen member states of the European Union. However, the manufacturer is given the option of funding additional tests, with optional safety equipment fitted. Manufacturers also have the option to fund tests, if tests on their car are not being funded by Euro NCAP. If a car is updated or superseded, the manufacturer can again fund a set of tests. In these circumstances, Euro NCAP will also publish the results from the tests funded by manufacturers.

No matter how the test is funded, care is taken to ensure that the cars tested are built to normal standards on the usual production line. This is usually achieved by purchasing the cars anonymously, through normal retail outlets. Other methods of selecting a car are possible, provided that Euro NCAP is satisfied that the car has not been specially prepared. Two examples of each car model are obtained. One is used for the frontal impact test and the other is used for the pedestrian tests and then the side impact test.

In both the frontal and side impact tests, child restraints recommended by the car manufacturer are used. Where the manufacturer does not recommend any particular child restraint, locally obtained restraints are used. Euro NCAP aims to encourage car manufacturers to take responsibility for providing good child protection in their cars.

TEST PROCEDURES

Euro NCAP assesses the protection for car occupants, in frontal impact and side impact and the protection afforded by the car's front to pedestrians. The test procedures used are based on those developed by the European Enhanced Vehicle-safety Committee (EEVC), for legislation in Europe. In the frontal and side impact tests, child dummies are installed in child restraints in the rear of the car. The installation and assessment procedures for the child restraints are based on those developed for ECE Regulation 44.03 (3).

Frontal Impact

In the frontal impact test, the car is impacted into an offset deformable barrier (ODB) at 64 km/h. The car is offset so that 40 percent of its width aligns with a deformable honeycomb barrier face mounted on a rigid block (Fig 1). In the front seats of the car are two instrumented Hybrid III dummies. Seated in the rear child restraints are a P1½ and a P3 dummy. With the exception of the impact speed and the presence of the child dummies, the test is the same as that specified in the new European Frontal Impact Directive (4).

Table 1.
Frontal Impact Car to Car Accident Impact Speed Related to the Proportion of Serious and Fatal Casualties Addressed

Accident Impact Speed* km/h	Casualties Addressed AIS≥3
50	Few
55	Just under ½
60	About ⅔

* 55 km/h approximates to an ODB test at 64 km/h

The impact speed of 64 km/h was chosen on the basis of accident analyses carried out for EEVC Working Group 11, which developed the European test procedure. An analysis of available frontal impact accident research concluded that a crash test, which replicated a car to car crash at 55 km/h, would address just under half of the serious and fatal casualties (AIS≥3). Reducing that speed to 50 km/h would address few such casualties, whereas, increasing the speed to 60 km/h would address about two thirds of them (Table 1). No direct comparison exists to relate the impact speed in an ODB test to its equivalent speed in a car to car crash, between similar cars. In the car to car impact, each car has to absorb its own impact energy. In an ODB test, the deformable barrier absorbs some of the impact energy. The amount of energy it absorbs depends upon how the car's structure loads the honeycomb. In comparative tests using a modern family size car, a car to car crash at 55 km/h was more severe than an ODB test at 65 km/h. This car loaded the deformable barrier relatively uniformly, such that the barrier would be quite efficient in absorbing energy. Future car designs are likely to load the deformable barrier at least as well. In this way, the designer can minimise the amount of energy his car has to absorb. Based on the available data, it can be seen that the Euro NCAP frontal impact test speed of 64 km/h is equivalent to a car to car impact at a speed of about 55 km/h.

Side Impact

The Euro NCAP side impact test is similar to that specified in the European Side Impact Directive (5). In the test the car is impacted on the driver's door by a 950 kg mobile deformable barrier (MDB), at 50 km/h (Fig 2). A EUROSID dummy, positioned in the driver's seat, is used to assess the car's performance. Again, child dummies are seated in the rear of the car. Although the European Directive allows different designs of barrier face to be used, Euro NCAP uses the same design for all its tests. Currently, the Cellbond Multi 2000 barrier face is specified.

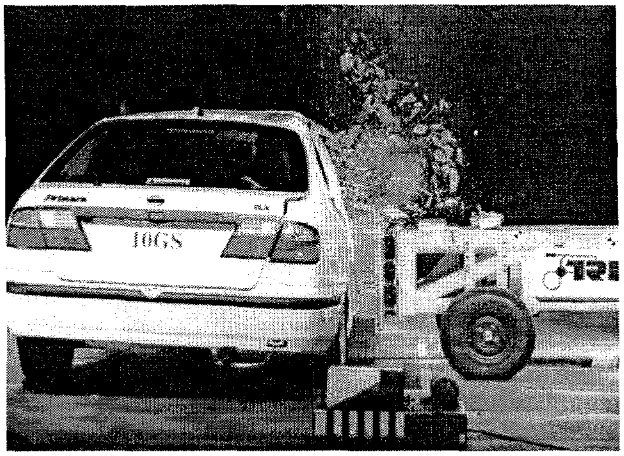

Figure 2. Euro NCAP Mobile Deformable Barrier Side Impact Test at 50 km/h

Child Restraints

In order to ensure consistency in the securing of the child and the restraint, the procedures developed for ECE Regulation 44.03 are used. The force used to install the restraints are limited to those that research has shown are used by parents. Instructions to use abnormal force during installation are ignored. In some cars, the rear seat belts can

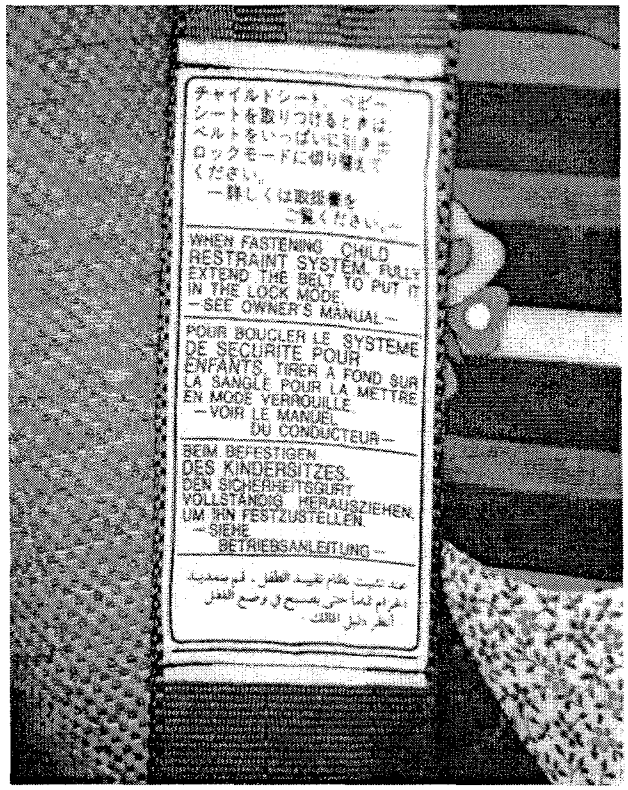

Figure 3. Multi-language Label on Rear Seat Belt Giving Instructions about Use with Child Restraints

be switched from emergency locking to automatic locking mode, for use with child restraints. Euro NCAP only uses such features, if there are clear use instructions on the belt (Fig 3).

The danger associated with the use of rearward facing child restraints, on seats equipped with airbags, is well established. Euro NCAP aims to see this hazard avoided. At some stage in the future, Euro NCAP may downgrade the rating of cars where this hazard exists. To avoid being downrated, cars with passenger seat airbags could be required to have automatic provision to disable the airbag when a child restraint is in place. A less significant downrating may be used where cars that have no automatic system but do have a clearly visible, explicit text warning. Currently, Euro NCAP is reporting what provision exists to avoid this hazard.

Pedestrian Testing

Pedestrian protection is assessed using the procedures recommended by the EEVC, for European legislation. A total of eighteen component tests are performed. Three leg form tests are carried out on the bumper and three upper leg form tests are performed on the bonnet leading edge. Head injury risk is assessed separately for adults and for children. For each, six head impact tests are performed in the relevant parts of the bonnet top area (Fig 4).

The EEVC procedure requires the assessor to seek out aggressive structures to test. However as most current car designs provide poor protection, Euro NCAP has instigated a change from phase three. To provide a reward to those who make some early improvement, manufacturers are allowed to choose nearly one half of the test sites. This enables them to benefit from areas that they have improved.

ASSESSMENT PROCEDURES

Frontal and Side Impact

In the frontal and side impact tests, fiftieth percentile male dummies are used, in the standard seating position. In the frontal test, the measured data is adjusted by the use of "modifiers" to extend the applicability of the assessment to different sized occupants and those sitting in different seating positions. Modifiers are also used in some cases where the dummies have no relevant instrumentation. Although the same concerns apply to some aspects of the side impact test, no methods have currently been developed to properly modify the side impact dummy data. After each test, the cars are measured and given a detailed examination. This examination provides the information upon which the modifiers are based.

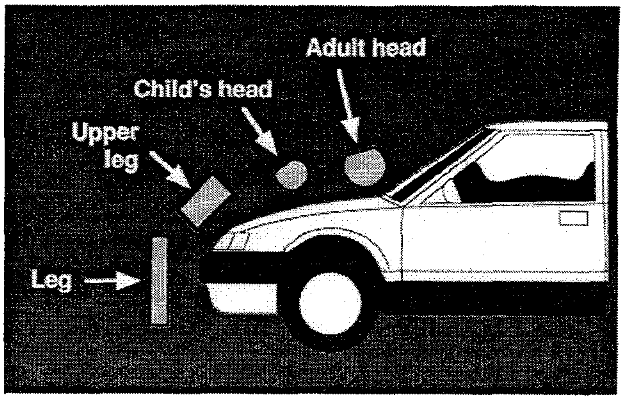

Figure 4. Euro NCAP Pedestrian Body Form Tests

The first stage of the assessment is based on the dummy data and deformation measurements. In the case of the frontal impacts, the modifiers are applied to the rating for the most relevant body region.

In the frontal and side impact tests, the rating for each body region falls within a colour coded band. These bands are coloured green, for best performance, through yellow, orange and brown, to red for worst performance (Table 2). In most cases, the boundaries between the brown and red bands are the criteria established by the EEVC. Where possible, the boundary between the green and yellow bands is set at the five percent probability level, for the same injury. Where there was no data to establish this boundary, it was set pragmatically, following discussions with industry representatives.

Table 2
Individual Body Region Rating in Frontal and Side Impact

Rating	Colour Code	Points Phases 1-2	Points Phases 3 >
Good	Green	4	4.00
Adequate	Yellow	3	2.67-3.99
Marginal	Orange	2	1.33-2.66
Weak	Brown	1	0.01-1.32
Poor	Red	0	0.00

After the modifiers are applied, an overall rating is established for frontal and side impact. For this purpose, body regions are grouped together and the rating for the grouped region is that of the worst performing sub-region. The grouped body regions are:

FRONTAL IMPACT
- Head and Neck
- Chest
- Knee, femur and Hip
- Leg, Foot and Ankle

SIDE IMPACT
- Head
- Chest
- Abdomen
- Pelvis

For each of these body regions points are awarded: four points for green down to zero points for red. In the first two phases of Euro NCAP, there were step changes in the points scale between the green/yellow and brown/red boundaries. From phase three, a linear scale has been adopted. In order to generate the final rating, the points for the two driver dummies are totalled and converted into a star rating (Table 3). If in the frontal impact, any part of the passenger obtains a lower score than for the driver, the passenger's score for that body region is used in the overall rating. A maximum score of 32 points is possible, for frontal and side impact protection.

Table 3
Conversion from Points to Overall Star Rating for Frontal and Side Impact

Star Rating	Points
★★★★	25 - 32
★★★	17 - 24
★★	9 -16
★	1 - 8
No Star	0

No attempt is made to weight the injury parameters on the basis of importance and no attempt is made to convert the test findings into measures of injury risk. It would be possible to apply different weights to life threatening and disabling injuries. This could also be done for severe and slight injuries and for frequently occurring and infrequently occurring injuries. However, it is unlikely that general agreement could be obtained for such weighting values. For example, individuals are more likely to be concerned about severity than frequency, whereas society has concerns for frequent and therefore costly injuries.

For conversions between test measurements and injury risk to be made, it is necessary for injury mechanisms to remain broadly similar. For car occupants, injury mechanisms have changed significantly in the recent past and can be expected to change in the future. It would, for example, be inappropriate to apply old data on injuries arising from hard contact with intrusion, to test data where the occupant loading came solely from the restraint system.

Euro NCAP makes no attempt to make such conversions. It simply presents the data on the basis of performance in crash tests. The intention is to encourage manufacturers to make improvements in all areas and to avoid concentrating attention on any individual area of the car.

Struck Through Stars

A change, introduced in phase three, results from concern that some cars are obtaining a relatively good final rating, despite poor performance in individual important body regions. This has most frequently been seen in the side impacts, where the chest was poorly protected. This concern is indicated by the final star being struck through, where the dummy data justifies a red rating, for a body region where fatal injuries are possible. These body regions are the head and chest, in frontal impact and the head, chest, abdomen and pelvis, in side impact.

Frontal Impact Injury Parameters

The measured parameters used in the frontal impact assessment are:

HEAD
- HIC_{36}
- Resultant acceleration, 3 msec exceedence

Note: Where there is no hard contact the rating is green

NECK
- Shear
- Tension
- Extension

CHEST
- Compression
- Viscous Criterion

UPPER LEG
- Femur force
- Knee slider

LOWER LEG
- Tibia Index
- Tibia compression

FOOT & ANKLE

Brake pedal rearward displacement

Footwell intrusion (not yet implemented)

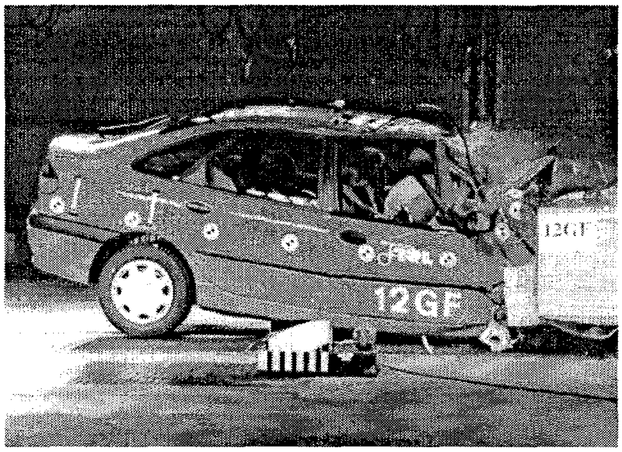

Figure 5. Unstable Head Contact on the Driver's Airbag.

Frontal Impact Modifiers

The measured parameters are adjusted, where necessary, by modifiers. In addition to their other functions, the modifiers allow some account to be taken of small vehicle and impact variations. Each modifier may reduce the score, for a body region by one or two points. These penalties are cumulative, but for any body region the maximum penalty is limited to two points. The frontal impact modifiers are:

HEAD

Unstable airbag head contact or airbag missed (-1 point)

If the centre of gravity of the head moves laterally outside the outer edge of the airbag, during the head's forward motion, contact is said to be unstable. In these circumstances, there is concern that the airbag might fail to protect in slightly different impact situations (Fig 5).

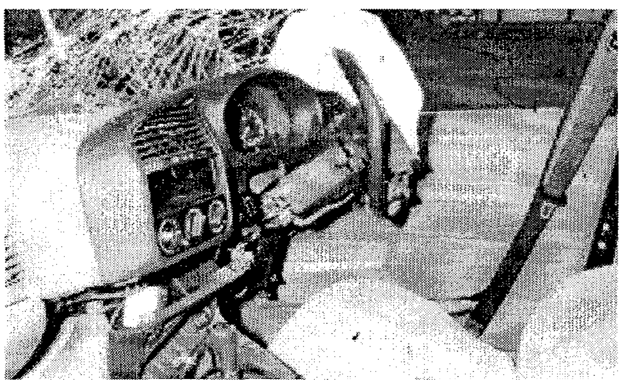

Figure 6. Steering Wheel Bent from Driver Chest Contact.

Steering wheel displacement > 80mm upwards or 100mm rearwards (0 points up to 10% below both limits to -1 point from 10% above either limit*)

This requirement is intended to help ensure that the airbag launch platform remains near to the design position

CHEST

Chest contact with the steering wheel (-1 point)

Direct chest loading from the steering wheel is poses an increased risk of injury (Fig 6).

A pillar displaced rearwards (0 points up to 100mm to –2 points from 200mm*)

A pillar displacement is used as an indicator of facia level intrusion. Intrusion is highly correlated with injury risk

Passenger compartment integrity (-1 point)

Where the passenger compartment becomes unstable, due to overloading, intrusion is likely to increase rapidly for small increases in impact severity and the repeatability is expected to be poor (Fig 7).

UPPER LEG

Stiffer structures in the knee impact area (-1 point)

The dummy's knees are set to a fixed spacing. Human occupants might sit with their knees in a variety of positions. If stiffer structures were impacted, knee loads would be greater (Fig 8).

Concentrated loading on the knee (-1 point)

Instrumentation in the upper leg check the protection for the femur, hip joint and pelvis. There is no

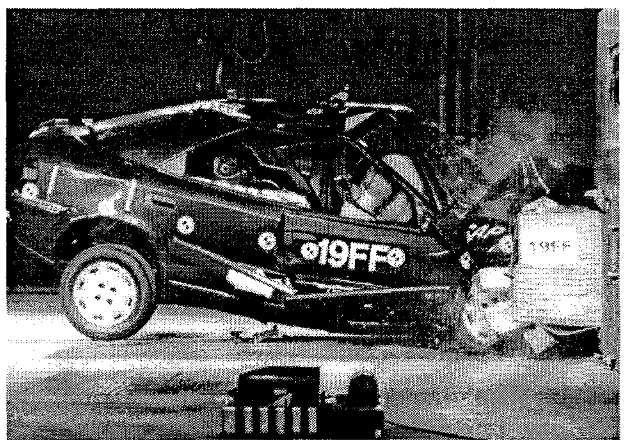

Figure 7. Loss of Passenger Compartment Integrity due to Overloading.

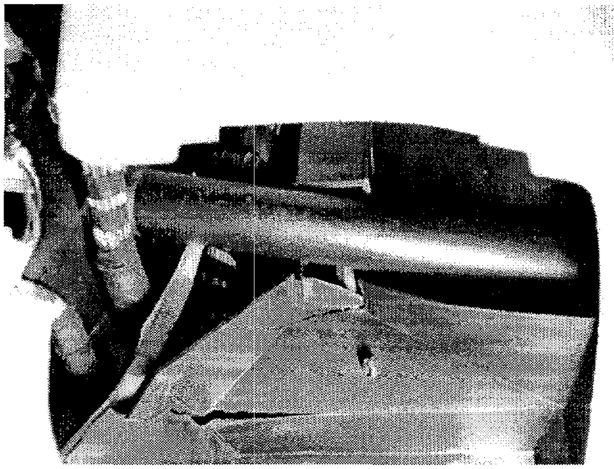

Figure 8. Steering Column Support in the Knee Impact Area Increases the Risk of Injury.

instrumentation to assess the risk to the knee from direct concentrated loading. Concentrated loading can injure the knee itself (Fig 9).

LOWER LEG

Upward brake pedal displacement > 80mm (0 points up to 10% below the limit to –1 point from 10% above the limit*)

Where the brake pedal is displaced upwards, the end of the pedal may impale the leg.

FOOT & ANKLE

Rupture of the footwell (-1 point)

Where there is significant rupture of the footwell area, there is an increased risk of injury from possible ingress

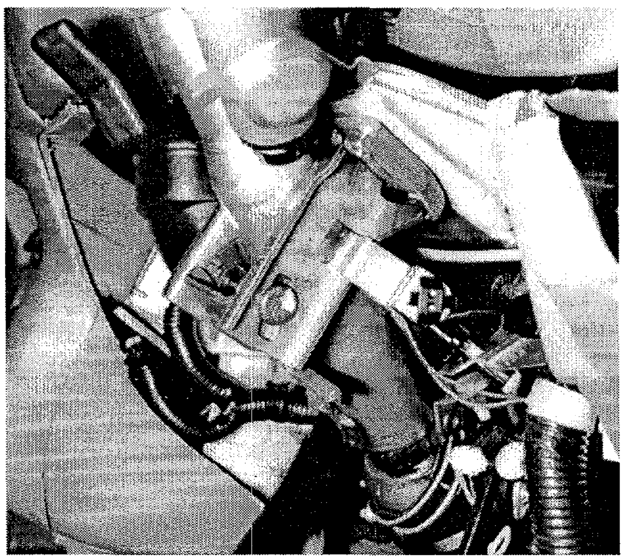

Figure 9. Column Adjuster Bracket Could Concentrate Loading on Part of the Knee.

of external objects

* These assessments have changed slightly following the adoption of sliding scales for Phase 3.

Side Impact Injury Parameters

The measured parameters used in the side impact assessment are:

HEAD

HIC_{36}

Resultant acceleration, 3 msec exceedence

Note: Where there is no hard contact the rating is green

CHEST

Compression

Viscous Criterion

ABDOMEN

Total abdominal force

PELVIS

Pubic symphysis force

Note: No modifiers are applied in side impact.

Child Injury Parameters

The assessment of child protection has developed through the early phases of Euro NCAP. Currently, the child protection assessment is not included within the overall assessment of occupant protection. The child protection parameters are:

Frontal Impact

1½ year old (P1½ dummy) and 3 year old (P3 dummy)

HEAD

Forward head excursion

NECK

Head vertical acceleration (P1½ only)

CHEST

Resultant acceleration

Vertical acceleration

Side Impact

1½ year old (P1½ dummy) and 3 year old (P3 dummy)

HEAD
Containment within the child restraint
Resultant acceleration, 3 msec exceedence

Pedestrian Injury Parameters

With the current level of pedestrian protection provided by most cars, it would be inappropriate to use the proposed EEVC requirements as a lower performance boundary along with an additional higher performance boundary. So that differences between cars can be identified and to increase the incentive for manufacturers, Euro NCAP, uses the EEVC limits as the upper performance boundary and has generated an additional lower performance boundary. During the first two phases, this lower boundary was taken to be the median of the results from test sites which failed to meet the EEVC limits. From phase three, the lower limits have been fixed. The parameters used to assess pedestrian protection are:

ADULT AND CHILD HEAD FORM
HIC_{36}

UPPER LEG FORM
Bending Moment
Sum of Forces

LEG FORM
Tibia Acceleration
Knee shear displacement
Knee bending angle

Each of the eighteen individual test sites are rated and awarded up to two points (Table 4). The points are then totalled, to obtain the overall star rating (Table 5). A problem arises when there is insufficient space to carry out the adult head impacts. For this reason, there have been small differences in the rating procedures used for each of the early phases.

Details of the assessment criteria are given in Appendix II.

Table 4
Pedestrian Body Form Ratings*

Rating	Colour Code	Points
Fair	Green	2.00
Weak	Yellow	0.01-1.99
Poor	Red	0.00

* This rating is for Phase 3 onwards. Slight differences exist for Phases 1 and 2.

Table 5
Conversion from Points to Overall Star Rating for Pedestrian Body Form Impacts*

Star Rating	Points
★★★★	28 - 36
★★★	19 - 27
★★	10 - 18
★	1 - 9
No Star	0

* This rating is for Phase 3 onwards. Slight differences exist for Phases 1 and 2.

MANUFACTURER INVOLVEMENT

When a decision has been made to test a particular size category of car, each manufacturer marketing a car in that size category is advised that his car might be chosen for test. The biggest selling variant is identified and the manufacturer is asked to confirm this. For those models selected for test, the manufacturer is asked what safety equipment is fitted as standard, on that variant, in all the fifteen member states of the European Union. As Euro NCAP only selects standard fit safety equipment, the manufacturer is given the option to fund additional tests on cars with optional safety equipment. If Euro NCAP decides not to include a car, again the manufacturer has the option of funding the tests. Whoever funds the test, Euro NCAP will publish the results.

Each manufacturer is asked to supply test set up data and they are invited to witness the set up and the test. They are asked to confirm that they are satisfied that both were carried out correctly. Following the test, they are supplied with a complete set of data and asked to report any concerns to the test laboratory.

When the assessment has been completed, the manufacturer is invited to a meeting to discuss the results of the tests, the inspection findings and to be advised of the assessment. The purpose of the meeting is to ensure that there were no undetected problems that might invalidate the rating. If there are concerns, manufacturers are invited to provide comparative data. This data is not published, nor is it intended to be used to modify the results from the Euro NCAP test. If problems cannot be resolved, the possibility exists for a further test to be performed, either at the expense of Euro NCAP or the manufacturer. Where a repeat test is carried out, the rating will be based on the results from that test alone. The manufacturer does not have the option to choose which data are published. The meeting is also used to discuss what data the manufacturer might be prepared to supply, for possible future developments of Euro NCAP.

In general, the data provided by manufacturers has shown that the test procedures have good repeatability. Where there have been differences between the manufacturer's and Euro NCAP's data, they can usually be explained. Loss of integrity of the passenger compartment, in frontal impact, is most commonly associated differences in deformation extent. This was expected and was one of the reasons for the inclusion of this criterion. In side impact, variations in the distribution of rib loading can often be related to small areas of stiff structure that load the chest slightly differently.

MEETINGS WITH THE MOTOR INDUSTRY

The Technical Working Group has regular meetings with the industry. Formally, it is through these meetings that information exchanges between Euro NCAP and the industry take place. Any manufacturer can be represented at these meetings, through their appropriate association. Initially these meetings were hostile, with industry representatives arguing against the existence of Euro NCAP. Over time the meetings have developed and have now become very useful. Euro NCAP seeks the industry views on its testing and assessment procedures and from this, a number of useful improvements have been made.

FUTURE DEVELOPMENTS

Although the test procedures used by Euro NCAP are comprehensive, they cannot fully assess the protection provided by a car. There are some particular deficiencies that Euro NCAP would like to address. It has always been recognised that the European side impact test does not adequately assess the protection provided for the head. Usually the head only impacts the side glass and possibly the B pillar. No assessment is made of the risk of injury from other parts of the car's interior or from structures outside the car. With the introduction of head protecting side impact airbags, Euro NCAP needs to be able to give due credit for effective systems. Consideration is currently being given to how this might be achieved. No such procedures exist to extend the applicability of the side impact results to different sized occupants and seating positions. What is clear is that some manufacturers are developing much of their protection to suit the standard seating position. There is also concern over the installation of "pelvis pushers," some of which may be used to unload the dummy's chest, in a manner that might not work for a human occupant. Euro NCAP may try to measure the shear force transmitted up the spine, with a view to developing a limit for it, in the future. When more is known about what influences Compatibility and when techniques are available to measure it, Euro NCAP would expect to adopt them. As car safety develops, it will be necessary for Euro NCAP to develop, whilst providing a consistent and stable environment for manufacturers to work within.

CRITICISMS OF EURO NCAP

As with other consumer information crash test programmes, the industry has voiced many criticisms of Euro NCAP. Although there has been substance to some of these, many have been unfounded or based on misunderstandings. Perhaps the most valid criticism is that Euro NCAP has not yet been able to test every available make of car, in a chosen size category. As funding increases, from additional sponsors, more cars can be tested and more complete coverage should be possible. As new models are launched, they may be tested, with their results added to that already published.

There has been criticism that only three test procedures are used, when car manufacturers test with many different configurations. Manufacturers do need to test using a range of impact configurations, if they are to ensure that their safety systems work correctly. Those who do this satisfactorily should produce cars that perform well in the Euro NCAP tests. Unfortunately, not all manufacturers carry out such extensive test programmes and the results of their tests are not available to the consumer.

It has been suggested that a frontal impact test speed of 64 km/h is unfair to large cars, because a smaller proportion of their kinetic energy can be absorbed by the deformable barrier face and because they will frequently impact lower mass cars. Such a test speed will make the cars stiffer and more aggressive to other cars. However, the deformable barrier face was introduced to overcome problems generated from the use of a rigid barrier. The deformable barrier test creates its own new problems but these have been minimised by limiting its depth and energy absorption capability. If large cars were to be tested at a lower speed, their ability to protect in the many crashes into immovable roadside obstacles would be reduced.

One reason for the development of the deformable barrier test was to highlight the problems caused by very non-homogenous front structures. Research is showing that such geometrical factors have a dominant influence over compatibility. In the short term at least, it is expected that the benefits from designing for the deformable barrier will outweigh any possible disadvantages of designing for the higher test speed. For the car's own occupants, there are clear advantages from testing at this speed.

There has been some concern over the subjective assessment used in the generation of some of the modifiers. In particular, those for passenger compartment integrity and the knee impact areas. Wherever possible, a clear objective definition has been given for each modifier. Where this has not been possible, a list of the aspects considered has been detailed. In most cases, the assessment is clear and unquestioned. In borderline cases, the manufacturer would be given the benefit of the doubt.

EURO NCAP TEST PHASES

The first phase of Euro NCAP covered seven cars in the supermini category. The results of these tests were published in February 1997. The second phase included tests on thirteen family cars and was published in July 1997. Small family cars have been tested for phase three, with the results being published in May 1998. Phase four will follow, with publication in September 1998, and will cover executive cars. Beyond that, additional phases and tests of models, which were not tested in the first four phases, are planned.

MANUFACTURER RESPONSE

From its first announcement, Euro NCAP has created a positive response from most manufacturers. They have immediately tried to make improvements to existing models and have increased the safety specifications of new designs. The rate of improvement has far exceeded expectations and the introduction of improvements has created problems for Euro NCAP regarding when cars are bought for testing. In a significant number of cases, optional safety equipment has been made standard throughout the European Union. In private discussions, many manufacturers state that a design requirement for new models is that the car will obtain four stars for occupant protection. This situation for pedestrians is not quite so good. However, it is clear that a number of manufacturers are taking positive steps towards improved pedestrian protection.

A number of manufacturers have also opted to fund Euro NCAP tests, either of new cars models or of cars with additional safety equipment. In some cases, manufacturers have requested that cars are tested in time for the results to be used when the car is first launched. Such arrangements are possible, provided that the cars meet the Euro NCAP requirements regarding how the cars for testing are obtained.

CONCLUSIONS

Euro NCAP was established to bring the benefits of consumer crash testing to the whole of Europe. Despite objections, the industry has responded by making rapid improvements to the cars they produce. Although some manufacturers are still negative about the programme, many others are positive. They have identified the marketing advantages which can be obtained by performing well and they appear determined to take advantage of them. There are still improvements which are necessary and difficult decisions have to be taken about how they can be incorporated. It can already be seen that the Euro NCAP tests have been accepted by most as the tests which are setting the standard for future crash protection. This places a great responsibility upon Euro NCAP to ensure that its requirements are both well founded and effective.

ACKNOWLEDGEMENTS

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APPENDIX I

SUMMARY RESULTS FROM EURO NCAP PHASE 1 SUPER-MINIS

Fiat Punto		Occupant	Pedestrian	
Overall Rating		★★	★	
Frontal and Side Impact Rating by Body Region				
Frontal Impact			Side Impact	
	Driver	F Pass		Driver
Head/Neck	**Marginal**	**Good**	Head	**Good**
Chest	**Weak**	**Adequate**	Chest	**Weak**
Upper Leg	**Weak**	**Good**	Abdomen	**Adequate**
Leg/Foot	**Poor**	**Adequate**	Pelvis	

Ford Fiesta		Occupant	Pedestrian	
Overall Rating		★★★	★	
Frontal and Side Impact Rating by Body Region				
Frontal Impact			Side Impact	
	Driver	F Pass		Driver
Head/Neck	**Adequate**	**Good**	Head	**Good**
Chest	**Marginal**	**Adequate**	Chest	**Weak**
Upper Leg	**Marginal**	**Adequate**	Abdomen	**Good**
Leg/Foot	**Weak**	**Good**	Pelvis	

Nissan Micra		Occupant	Pedestrian	
Overall Rating		★★	★★	
Frontal and Side Impact Rating by Body Region				
Frontal Impact			Side Impact	
	Driver	F Pass		Driver
Head/Neck	**Good**	**Good**	Head	**Good**
Chest	**Marginal**	**Adequate**	Chest	**Adequate**
Upper Leg	**Poor**	**Good**	Abdomen	**Poor**
Leg/Foot	**Poor**	**Good**	Pelvis	**Adequate**

Renault Clio		Occupant	Pedestrian	
Overall Rating		★★	★	
Frontal and Side Impact Rating by Body Region				
Frontal Impact			Side Impact	
	Driver	F Pass		Driver
Head/Neck	**Marginal**	**Good**	Head	**Good**
Chest	**Weak**	**Adequate**	Chest	**Poor**
Upper Leg	**Poor**	**Good**	Abdomen	**Marginal**
Leg/Foot	**Weak**	**Adequate**	Pelvis	

Rover 100		Occupant	Pedestrian	
Overall Rating		★	★★	
Frontal and Side Impact Rating by Body Region				
Frontal Impact			Side Impact	
	Driver	F Pass		Driver
Head/Neck	**Poor**	**Good**	Head	**Good**
Chest	**Weak**	**Good**	Chest	**Poor**
Upper Leg	**Poor**	**Adequate**	Abdomen	**Poor**
Leg/Foot	**Poor**	**Good**	Pelvis	**Adequate**

Vauxhall/Opel Corsa		Occupant		Pedestrian
Overall Rating		★★		★
Frontal and Side Impact Rating by Body Region				
Frontal Impact			Side Impact	
	Driver	F Pass		Driver
Head/Neck	**Adequate**	**Poor**	Head	**Good**
Chest	**Marginal**	**Adequate**	Chest	**Adequate**
Upper Leg	**Poor**	**Weak**	Abdomen	**Weak**
Leg/Foot	**Marginal**	**Adequate**	Pelvis	

VW Polo		Occupant		Pedestrian
Overall Rating		★★★		★
Frontal and Side Impact Rating by Body Region				
Frontal Impact			Side Impact	
	Driver	F Pass		Driver
Head/Neck	**Adequate**	**Good**	Head	**Good**
Chest	**Marginal**	**Adequate**	Chest	**Poor**
Upper Leg	**Adequate**	**Good**	Abdomen	**Adequate**
Leg/Foot	**Poor**	**Good**	Pelvis	**Adequate**

SUMMARY RESULTS FROM EURO NCAP PHASE 2 FAMILY CARS

Audi A4		Occupant		Pedestrian
Overall Rating		★★		★★
Frontal and Side Impact Rating by Body Region				
Frontal Impact			Side Impact	
	Driver	F Pass		Driver
Head/Neck	**Good**	**Good**	Head	**Good**
Chest	**Weak**	**Marginal**	Chest	**Poor**
Upper Leg	**Weak**	**Good**	Abdomen	**Adequate**
Leg/Foot	**Poor**	**Adequate**	Pelvis	**Adequate**

BMW 3 Series		Occupant		Pedestrian
Overall Rating		★★		★★
Frontal and Side Impact Rating by Body Region				
Frontal Impact			Side Impact	
	Driver	F Pass		Driver
Head/Neck	**Marginal**	**Good**	Head	**Good**
Chest	**Poor**	**Marginal**	Chest	**Weak**
Upper Leg	**Poor**	**Good**	Abdomen	**Poor**
Leg/Foot	**Poor**	**Good**	Pelvis	**Good**

Citroen Xantia		Occupant		Pedestrian
Overall Rating		★★		★
Frontal and Side Impact Rating by Body Region				
Frontal Impact			Side Impact	
	Driver	F Pass		Driver
Head/Neck	**Marginal**	**Good**	Head	**Poor**
Chest	**Weak**	**Marginal**	Chest	**Poor**
Upper Leg	**Poor**	**Good**	Abdomen	**Marginal**
Leg/Foot	**Poor**	**Adequate**	Pelvis	**Good**

Ford Mondeo		Occupant		Pedestrian
Overall Rating		★★★		★★
Frontal and Side Impact Rating by Body Region				
Frontal Impact			Side Impact	
	Driver	F Pass		Driver
Head/Neck	**Good**	**Good**	Head	**Good**
Chest	**Weak**	**Marginal**	Chest	**Poor**
Upper Leg	**Poor**	**Good**	Abdomen	**Good**
Leg/Foot	**Poor**	**Adequate**	Pelvis	**Good**

Mercedes Benz C Class	Occupant	Pedestrian		
Overall Rating	★★	★★		
Frontal and Side Impact Rating by Body Region				
Frontal Impact			Side Impact	
	Driver	F Pass		Driver
Head/Neck	**Adequate**	**Good**	Head	**Good**
Chest	**Weak**	**Marginal**	Chest	**Weak**
Upper Leg	**Poor**	**Good**	Abdomen	**Marginal**
Leg/Foot	**Poor**	**Adequate**	Pelvis	**Good**

Nissan Primera	Occupant	Pedestrian		
Overall Rating	★★★	★★		
Frontal and Side Impact Rating by Body Region				
Frontal Impact			Side Impact	
	Driver	F Pass		Driver
Head/Neck	**Good**	**Good**	Head	**Good**
Chest	**Adequate**	**Marginal**	Chest	**Weak**
Upper Leg	**Marginal**	**Good**	Abdomen	**Adequate**
Leg/Foot	**Poor**	**Good**	Pelvis	**Adequate**

Peugeot 406	Occupant	Pedestrian		
Overall Rating	★★	★★		
Frontal and Side Impact Rating by Body Region				
Frontal Impact			Side Impact	
	Driver	F Pass		Driver
Head/Neck	**Adequate**	**Good**	Head	**Good**
Chest	**Marginal**	**Marginal**	Chest	**Weak**
Upper Leg	**Poor**	**Good**	Abdomen	**Good**
Leg/Foot	**Poor**	**Good**	Pelvis	**Marginal**

Renault Laguna	Occupant	Pedestrian		
Overall Rating	★★★	★★		
Frontal and Side Impact Rating by Body Region				
Frontal Impact			Side Impact	
	Driver	F Pass		Driver
Head/Neck	**Adequate**	**Good**	Head	**Good**
Chest	**Adequate**	**Good**	Chest	**Poor**
Upper Leg	**Poor**	**Good**	Abdomen	**Adequate**
Leg/Foot	**Poor**	**Adequate**	Pelvis	**Good**

Rover 600	Occupant	Pedestrian		
Overall Rating	★★	★★		
Frontal and Side Impact Rating by Body Region				
Frontal Impact			Side Impact	
	Driver	F Pass		Driver
Head/Neck	**Adequate**	**Good**	Head	**Good**
Chest	**Poor**	**Adequate**	Chest	**Poor**
Upper Leg	**Poor**	**Good**	Abdomen	**Poor**
Leg/Foot	**Poor**	**Adequate**	Pelvis	**Good**

Saab 900	Occupant	Pedestrian		
Overall Rating	★★	★★		
Frontal and Side Impact Rating by Body Region				
Frontal Impact			Side Impact	
	Driver	F Pass		Driver
Head/Neck	**Adequate**	**Good**	Head	**Good**
Chest	**Poor**	**Marginal**	Chest	**Poor**
Upper Leg	**Weak**	**Good**	Abdomen	**Weak**
Leg/Foot	**Weak**	**Good**	Pelvis	**Adequate**

Vauxhall/Opel Vectra			Occupant	Pedestrian
Overall Rating			★★★	★★
Frontal and Side Impact Rating by Body Region				
Frontal Impact			Side Impact	
	Driver	F Pass		Driver
Head/Neck	**Adequate**	**Good**	Head	**Good**
Chest	**Marginal**	**Weak**	Chest	**Poor**
Upper Leg	**Good**	**Good**	Abdomen	**Marginal**
Leg/Foot	**Poor**	**Adequate**	Pelvis	**Good**

VW Passat			Occupant	Pedestrian
Overall Rating			★★★	★★
Frontal and Side Impact Rating by Body Region				
Frontal Impact			Side Impact	
	Driver	F Pass		Driver
Head/Neck	**Adequate**	**Good**	Head	**Good**
Chest	**Good**	**Marginal**	Chest	**Adequate**
Upper Leg	**Marginal**	**Adequate**	Abdomen	**Weak**
Leg/Foot	**Poor**	**Adequate**	Pelvis	**Adequate**

Volvo S40			Occupant	Pedestrian
Overall Rating			★★★★	★★
Frontal and Side Impact Rating by Body Region				
Frontal Impact			Side Impact	
	Driver	F Pass		Driver
Head/Neck	**Good**	**Good**	Head	**Good**
Chest	**Marginal**	**Marginal**	Chest	**Adequate**
Upper Leg	**Good**	**Good**	Abdomen	**Adequate**
Leg/Foot	**Marginal**	**Good**	Pelvis	**Adequate**

Note: The ratings used in Phases 1 and 2 are slightly different from those adopted for Phase 3 onwards.

APPENDIX II

Injury Parameters

The main injury parameters are based on bio-mechanical data. Others use vehicle deformation data. For frontal and side impact a lower performance boundary has been set at the limits proposed by EEVC. An upper performance boundary has also been set. Where possible, this has been set to the five percent probability level, for the same injury. The lower performance boundary is the point at which the rating changes from Poor (Red) to Weak (Brown). The upper performance boundary is at the point at which the rating changes from Adequate (Yellow) to Good (Green).

For pedestrian protection, the EEVC limits are used for the upper performance boundary with a lower limit generally set at around the average value for cars in phases one and two.

Frontal Impact Performance Boundaries

Head	Lower	Upper
HIC_{36}	1000	650
Res acc (3 msec)*	72 g	88 g

* This criterion has changed slightly, with the adoption of sliding scales for phase three.

Neck	Lower	Upper
Shear	3.1 kN @ 0 msec 1.5 kN @ 25 – 35 msec 1.1 kN @ from 45 msec	1.9 kN @ 0 msec 1.2 kN @ 25 - 35 msec 1.1 kN @ from 45 msec
Tension	3.3 kN @ 0 msec 2.9 kN @ 35 msec 1.1 kN @ from 60 msec	2.7 kN @ 0 msec 2.3 kN @ 35 msec 1.1 kN @ from 60 msec
Extension	57 Nm	42 Nm

Chest	Lower	Upper
Compression	50 mm	22 mm
Viscous Criterion	1.0 m/sec	0.5 m/sec

Upper Leg	Lower	Upper
Femur force	9.07 kN @ 0 msec 7.56 kN @ from 10 msec	3.8 kN
Knee slider	15 mm	6 mm

Lower Leg	Lower	Upper
Tibia Index	1.3	0.4
Tibia compression	8 kN	2 kN

Foot & Ankle	Lower	Upper
Brake pedal rearward displacement	200 mm	100 mm
Footwell intrusion**	200 mm	100 mm

** This criterion has not yet been implemented

Side Impact Performance Boundaries

Head	Lower	Upper
HIC_{36}	1000	650
Res acc (3 msec)*	72 g	88 g

* This criterion has changed slightly, with the adoption of sliding scales for phase three.

Chest	Lower	Upper
Compression	42 mm	22 mm
Viscous Criterion	1.0 m/sec	0.32 m/sec

Abdomen	Lower	Upper
Total Force	2.5 kN	1.0 kN

Pelvis	Lower	Upper
Pubic Symphysis Force	6.0 kN	3.0 kN

Child Injury Performance Boundaries

Frontal Impact

Head	Lower	Upper
Forward Excursion (forward facing) (rearward facing)	550 mm* 600 mm**	550 mm* 600 mm**

* and shall not contact the car interior
** no compression load is to be imposed on the crown of the head

Neck	Lower	Upper
Head Vert Comp Acc (3 msec)*	None	20g

* P1½ dummy only

Chest	Lower	Upper
Resultant Acceleration	55 g	41 g
Vertical Acceleration	30 g	23 g

Side Impact

Head	Lower	Upper
Containment	None	Within the restraint
Res acc (3 msec)	None	80 g

Pedestrian Injury Parameters

Head Form	Lower*	Upper
HIC_{36}	1500	1000

Upper Leg Form	Lower*	Upper
Bending Moment	400 Nm	220 Nm
Sum of Forces	7.0 kN	4.0 kN

Leg Form	Lower*	Upper
Tibia Acceleration	230 g	150 g
Knee Shear Displacement	7.5 mm	6 mm
Knee Bending Angle	30°	15°