Factors related to serious injury in post ncap european cars involved in frontal crashes

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FACTORs RELATED TO SERIOUS INJURY IN POST-NcAP EUROPEAN CARS INVOLVED IN FRONTAL CRASHES

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ABSTRACT

This study examined the relationship between EuroNCAP ratings for body region protection and real world injury risk for 653 belted drivers in frontal crashes. It was also able to comment on further improvements in crash protection for post-EuroNCAP cars. Protection for the head and lower leg appeared good. In terms of life threatening injury, results showed a need to prioritise chest protection, whilst for impairment, protection for the upper leg and ankle/foot should be considered. The EuroNCAP body region scoring system reflects trends in real crash injury risks to all body regions, except for the chest, where there is no clear trend. More generally, further development in the testing regime could usefully concentrate on a restraint system test and the use of smaller dummies seated appropriately, rather than an increase of the test speed.

The Frontal crash test regulation in Europe uses a deformable crash barrier offset to the driver’s side of the vehicle (UN ECE, 1998). Essentially, it examines vehicle structural performance and was developed by the EEVC (Lowne, 1994), because 2/3 of serious injuries were found to occur with passenger compartment intrusion, which was associated with about 2/3 of serious and fatal injuries (Hobbs, 1992). The EuroNCAP consumer crash test procedure also utilises an offset crash but at a higher severity than the regulation test (Hobbs and McDonough, 1998). This contrasts with the U.S. NCAP procedure which still uses a fully overlapping barrier. EuroNCAP was established in 1997 and is now backed by five European Governments, the European Commission and motoring and consumer organisations in every EU country.
Current wisdom suggests that the consumer crash test is now driving safety performance. Indeed, there have been demonstrated improvements in crash safety since publication of the first EuroNCAP results in 1997 and at least one vehicle model has been discontinued by its manufacturer due to poor performance in the test. Certainly, it has encouraged the fitment of driver airbags, as the head protection criteria is difficult to pass without them. The result has been an overall improvement in crash protection in frontal impacts as shown by recent crash research (Lenard et al, 1998a; Frampton et al, 2000; Frampton et al, 2002). Specifically, head protection has improved (Kirk et al, 2002).

EuroNCAP is continually evolving, the star rating and additions of a pedestrian test and side impact pole test being some examples. As more and more cars achieve the coveted 5 star rating, the question remains as to how real world crash data can give pointers to the evolution of the testing system. One way is to examine modern vehicles and the crash and occupant variables that contribute to continuing serious injury. For example, in cars fitted with airbags, why do serious head injuries still occur?

Correlation between EuroNCAP scores and real world injury outcome has already been tested (Lie, 2000). That work showed a valid relationship between overall star ratings and real world crash protection. This study examines the frontal crash component of the test with a focus on the accuracy of dummy outputs and “modifiers” to predict injury outcome. The research question is; “what are the conditions where serious injury now occurs in modern cars and does a single point test, with one size of dummy, accurately predict the risk outcome?” In other words, how can EuroNCAP be further developed to ensure continued improvements in crash protection?

METHOD

In-depth crash injury data collected by the UK Co-operative Crash Injury Study (CCIS) was used (Mackay et al, 1985) to compare the injury outcomes in real-world crashes with the predicted levels of injury protection provided by EuroNCAP. The CCIS data are sampled on vehicle age, vehicle damage and injury outcome. To be included in the database, the crash must have included at least one car that was at most seven years old at the time of the crash, was towed away from the crash scene and contained an injured occupant. The data are also collected within a stratified sample which is biased towards ‘fatal’ and ‘serious’ injury outcome crashes. Of all crashes occurring in the geographical sampling regions, approximately 80% of all fatal and serious crashes, and 10-15% of slight injury crashes are
investigated. Crashes that occurred between 1995 and 2002 were analysed.

Vehicles were selected on the basis of frontal impact. Multiple impact crashes were also included providing that the frontal impact was the most severe. Endswipe impacts were not included, since they represent only a small proportion of frontal impacts, and are not easily compared with EuroNCAP crash tests.

Vehicles were only selected if they had been subject to a EuroNCAP frontal crash test and contained a belted driver. This information was obtained from the EuroNCAP website, www.euroncap.com. Only models fitted with the same safety devices (e.g. airbags, seatbelt pretensioners) as the corresponding EuroNCAP-tested model were included.

In addition to the star rating it awards to each model, EuroNCAP also awards a protection score for the head, neck, thorax, upper leg (left and right), lower leg (left and right) and feet. The protection offered to each region is described by a five-point scale, “Poor” (lowest), “Weak”, “Marginal”, “Adequate” and “Good” (highest). These body region protection scores provided the basis for comparison between the EuroNCAP results and the real-world data.

Generally, drivers are more at risk from injury in frontal impacts than front seat passengers. Therefore this study only looked at drivers’ injuries. There were 653 drivers in the CCIS database who had been involved in a crash when driving a EuroNCAP car. Injuries to the cranium and its contents were compared to the EuroNCAP “head” scores; thoracic injuries to the chest rating; hip, thigh and knee injuries to the upper leg rating; leg injuries to the lower leg rating and ankle/foot injuries to the foot protection rating. For the head and thorax, AIS 3+ injuries were classed as “serious”. For the lower extremities, AIS 2+ injuries were classed as “serious” to include lower limb fracture and injuries which carried a high impairment, rather than threat to life value.

The CCIS sampling procedure means that non-injury cases are under-represented in the data; for that reason, the analysis of this data does not purport to show absolute risk of injury, rather, it is designed to provide a comparison of real injury distribution between NCAP body protection ratings for cars which were selected using similar sampling criteria. In addition, groups of cars with different protection ratings were checked for comparability on main injury predictors such as crash severity, overlap and driver age. The analysis results were tested for statistical significance where appropriate using the Chi-Square and Mann-Whitney U tests. In each case, the null hypotheses of
no difference between groups was rejected if the probability (p) associated with the test statistic was less than 0.05.

Injury outcome was rated using the AIS 90 (AAAM, 1990). The Equivalent test Speed (ETS) was used as a measure of crash severity. ETS is the vehicle delta v, calculated on the assumption that deformation was caused by impact with a fixed rigid barrier (Lenard et al., 1998b). In the text, frontal “overlap” refers to the percentage of the vehicle front end directly impacted by an opposing car or other object.

RESULTS

SAMPLE CHARACTERISTICS -

![Graph showing year of manufacture of Real-World EuroNCAP Sample](image)

Fig 1 - Year of Manufacture of Real-World EuroNCAP Sample

There were 653 cars in the real-world study sample which had been EuroNCAP tested since the inception of the programme in 1997. Figure 1 shows the spread by year of manufacture for those vehicles. The overall majority of cars were manufactured between 1996 and 2001 with smaller numbers from model years 1994-95 and 2002. The sample therefore represents a good number of relatively modern vehicles.

HEAD INJURIES - All but two of the EuroNCAP cars in the sample were considered to provide at least “marginal” protection to the head and there were no cars classed as “poor”. In the total sample of 653 cars, the rate of AIS 2+ head injury was 4% and the AIS 3+ rate was 1%.

Figure 2 shows how drivers with AIS 3+ head injuries were distributed among head protection classes compared to the distribution of head protection classes for all drivers. The weak and marginal categories have been grouped together due to small numbers in the “weak” group.
The weak/marginal group formed 11% of the overall sample but contained 25% of serious head injury cases. Serious head injury was therefore over-represented in this group. The “good” group formed 34% of the overall sample but contained 25% of the serious injury cases. Serious head injury was thus under-represented in this group. The “adequate” group contained a number of serious head injury cases comparable to its proportion of the overall sample. Although the number of serious head injury cases is small, there appears to be a trend for less to occur in the cars rated as “good” and more in those rated as “weak/marginal”.

Only 8 occupants in the sample sustained serious (AIS 3+) head injuries. Those 8 cases were examined in more detail to ascertain the exact causes of injury.

Of the 8 cases, one was a severe impact (Delta-v 89 km/h) and three were impacts with heavy trucks where injury occurred from head impact to the truck. In the remaining 4 cases, injury was caused by head impact with an intruding A-pillar. Two of those cars were classed as “adequate” for head protection, one as “good” and one as “marginal”.

CHEST INJURIES - There were few cars which were given chest protection scores of either “Weak” or “Good”. The scores were therefore grouped as shown in figure 3. In the total sample of 653 cars the rate of AIS 2+ chest injury was 10% and the AIS 3+ rate was 4%.

Figure 3 shows how drivers with AIS 3+ chest injuries were distributed among chest protection classes compared to the distribution of chest protection classes for all drivers.
The poor/weak group formed 29% of the overall sample but contained only 15% of serious chest injury cases. Serious chest injury was therefore under-represented in this group. The “marginal” group formed 38% of the overall sample but contained 52% of the serious injury cases. Serious chest injury was thus over-represented in this group. The “adequate/good” group contained a number of serious chest injury cases comparable to its proportion of the overall sample. There does not appear to be a trend for the serious chest injuries to occur more often in the groups classed as lower protection.

In order to check for other confounding factors it was necessary to establish whether the protection class groups were comparable in terms of distribution of the other main injury predictors, such as crash severity, overlap and driver age. Chi-square tests were performed on the distributions of these variables across the relevant protection groupings, and no significant differences in the distributions were found for ETS (p=0.070), overlap (p=0.315), and age (p=0.070).

Factors related to chest injury - The second aim of this study was to examine the crash conditions and occupant variables related to serious injury outcome in modern vehicles. This part of the study used the whole sample of EuroNCAP cars and comparisons were drawn between those cars where the driver sustained only slight chest injury or no chest injury and those where a serious (AIS 3+) chest injury was sustained.

The distributions of ETS in the No/slight injury and serious (AIS 3+) groups were compared using the Mann-Whitney U test. The mean ETS of the serious group (41 km/h) was significantly higher (p<0.005) than the No/slight injury group (28 km/h), indicating that ETS is an important factor affecting chest injury outcome.
The distribution of overlap of both injury severity groups is shown in figure 4. Full overlap accounted for some 40% of cases with low chest injury severity and 55% of those with serious chest injury. There were more left offset impacts in the low injury severity group.

![Figure 4 - Distribution of Overlap for No/Slight and Serious Chest Injuries](image)

The mean age of the serious group (46) was not significantly different (p=0.208) to the No/slight injury group (40) using the Mann-Whitney U test.

The distribution of gender between the no/slight and serious injury groups is shown in figure 5. A chi-squared test shows the difference in distribution is not statistically significant (p=0.383).

![Figure 5 - Driver Gender Split by Chest Injury Severity](image)

The CCIS data also records the likely cause of injury for each body region. The distribution of injury causation is shown in figure 6. Slight injuries were those classed as AIS 1 and 2.
Most slight injuries were classed as bruising and abrasions and over 80% were caused solely by the seat belt webbing. 51% of serious chest injuries were caused by seat belt loads with some 40% by impacting the steering wheel.

UPPER LEG INJURIES - The crash data showed vehicles well represented in all protection categories. In the total sample of 653 cars the rate of AIS 2+ upper leg injury was 6% and the AIS 3+ rate was 4%. Injuries of AIS 3+ were mainly femur fractures.

Figure 7 shows how drivers with AIS 2+ upper leg injuries were distributed among upper leg protection classes compared to the distribution of upper leg protection classes for all drivers.

The poor group formed 30% of the overall sample but contained 42% of serious upper leg injury cases. Serious upper leg injury was therefore over-represented in this group. The “weak” group formed 18% of the overall sample but contained only 11% of the serious injury cases. Serious upper leg injury was
thus under-represented in this group. The “marginal” and “adequate” groups contained a number of serious upper leg injury cases comparable to their proportions in the overall sample. The “good” group formed 9% of the overall sample but contained only 5% of serious upper leg injury cases. Serious upper leg injury was therefore under-represented in this group.

As with the chest injury analysis, it was necessary to establish whether the protection class groups were comparable in terms of distribution of the other main injury predictors, such as crash severity, overlap and driver age. Chi-square tests showed no significant difference in the distributions of ETS (p=0.685) and overlap (p=0.479). However, the median age of drivers in the “good” upper leg protection group was significantly higher than the other groups (p=0.023).

Factors related to upper leg injury - The crash conditions and occupant variables related to upper leg injury outcome were examined for this sample of modern cars. Comparisons were drawn between cars where the driver sustained only slight or no upper leg injury and those where an AIS 2+ injury was sustained.

The distributions of ETS in the No/slight injury and serious (AIS 2+ for upper leg injury) groups were compared using the Mann-Whitney U test. The mean ETS of the serious group (45 km/h) was significantly higher (p<0.005) than the No/slight injury group (28 km/h) indicating that ETS is an important factor affecting upper leg injury outcome.

![Figure 8 – Overlap Distribution by Upper Leg Injury Severity](image)

The distribution of overlap of both injury severity groups is shown in figure 8. Full overlap accounted for 40% of cases with no/slight injury and 46% of those with AIS 2+ injury. There were more left offset impacts in the low injury severity group.
The mean age of the serious injury group (40) was not significantly different (p=0.662) to the no/slight injury group (40) using the Mann-Whitney U test.

The distribution of gender between the no/slight and serious upper leg injury groups is shown in figure 9. The results suggest that women are more likely to sustain a serious (AIS 2+) upper leg injury than men. This is borne out by the Chi-square test result (p=0.003).

Figure 9 - Driver Gender Split by Upper Leg Injury Severity

Facia intrusion was examined in relation to injury to this body region and is shown in figure 10.

Figure 10 - Facia Intrusion by Upper Leg Injury Severity

Figure 10 shows the static intrusion associated with the different levels of upper leg injury. Most of the cases (90%) with slight or no injury had low intrusion levels (0-5cm). By comparison, most of the cases with AIS 2+ injury showed intrusion greater than 5cm. It should be noted however that 38% of drivers with AIS 2+ upper leg injury had experienced intrusion of only 0-5 cm.
LOWER LEG INJURIES - In the total sample of 653 cars, the rate of AIS 2+ lower leg injury was 1% and the AIS 3+ rate was 0.5%.

Figure 11 shows how drivers with AIS 2+ lower leg injuries were distributed among lower leg protection classes compared to the distribution of lower leg protection classes for all drivers.

![Graph showing distribution of EuroNCAP Lower Leg Protection Class compared to AIS 2+ Lower Leg Injury Distribution](image)

Figure 11 - Distribution of EuroNCAP Lower Leg Protection Class (N=653) Compared to AIS 2+ Lower Leg Injury Distribution (N=8)

The poor group formed 17% of the overall sample but contained 25% of serious lower leg injury cases. Serious lower leg injury was therefore over-represented in this group. The “weak” group formed 6% of the overall sample but contained 37.5% of the serious injury cases. Serious lower leg injury was highly over-represented in this group. The “marginal” group formed 24% of the overall sample but only contained 12.5% of the serious injury cases. Serious lower leg injury was therefore under-represented in this group. The “adequate” group contained a number of serious lower leg injury cases comparable to its proportion in the overall sample. The “good” group formed 26% of the overall sample and contained no serious lower leg injury cases. Although the number of AIS 2+ injury cases is small, there appears to be a trend for more of those injuries to occur when the car was rated as “poor” or “weak” than if it was rated “marginal” or “good”.

Only 8 drivers in the sample sustained AIS 2+ lower leg injury. Those 8 cases were examined in more detail to ascertain the exact causes of injury. Five drivers were in cars classed as “poor” and “weak” by EuroNCAP, one in the “marginal” group and two in the “adequate” group. Injury sources for the lower leg included the pedals, facia, footwell and 3 drivers with injury from bracketry under the steering column cladding.
ANKLE AND FOOT INJURIES - The crash data showed vehicles well represented in all protection categories. In the total sample of 653 cars the rate of AIS 2+ ankle/foot injury was 6%. Of the 40 AIS 2+ injuries, 32/40 (80%) had the potential for long term impairment of function.

Figure 12 shows how drivers with AIS 2+ ankle/foot injuries were distributed among foot protection classes compared to the distribution of foot protection classes for all drivers.

![Figure 12 - Distribution of EuroNCAP Foot Protection Class (N=653) Compared to AIS 2+ Ankle/Foot Injury Distribution (N=38)](image)

The “poor” group formed 19% of the overall sample but contained 27% of serious ankle/foot injury cases. Serious ankle/foot injury was therefore over-represented in this group. The “weak” group formed 29% of the overall sample and contained 42% of the serious injury cases. Serious ankle/foot injury was thus over-represented in this group. The “marginal” group formed 19% of the overall sample and 13% of the serious injury cases. Serious ankle/foot injury was thus slightly under-represented in this group. The “adequate” group formed 16% of the overall sample but contained only 5% of serious ankle/foot injury cases. Serious ankle/foot injury was therefore highly under-represented in this group. The “good” group formed 17% of the overall sample but contained only 13% of serious ankle/foot injury cases. Serious ankle/foot injury was therefore under-represented in this group.

It was necessary to establish whether the protection class groups were comparable in terms of distribution of the other main injury predictors, such as crash severity, overlap and driver age. Chi-square tests showed no significant difference in the distributions of ETS (p=0.279) and overlap (p=0.796). However, the drivers of cars with “good” foot protection scores were significantly younger than drivers of any other group (p=0.007).
Factors related to ankle/foot injury - The crash conditions and occupant variables related to ankle/foot injury outcome were examined for this sample of modern cars. Comparisons were drawn between cars where the driver sustained only slight or no ankle/foot injury and those where an AIS 2+ injury was sustained.

The distributions of ETS in the No/slight injury and serious (AIS 2+ for ankle/foot injury) groups were compared using the Mann-Whitney U test. The mean ETS of the serious group (39 km/h) was significantly higher (p<0.005) than for the No/slight injury group (28 km/h) indicating that ETS is an important factor affecting ankle/foot injury outcome.

The distribution of overlap of both injury severity groups is shown in figure 13. Full overlap accounted for 40% of cases with no/slight injury and 50% of those with AIS 2+ injury. There were more left offset impacts in the low injury severity group.

![Figure 13 - Overlap Distribution by Ankle/Foot Injury Severity](image)

The mean age of the occupants with no/slight injury was 40, whilst the mean age of the occupants with serious injury was 42. A Mann-Whitney U test shows that this difference is statistically insignificant (p=0.760).

The distribution of gender between the no/slight and serious ankle/foot injury groups is shown in figure 14. As was the case with upper leg injuries, it would appear that women are more likely to sustain serious ankle/foot injury than men. This is supported by a Chi-square test (p=0.003)
Footwell intrusion was examined in relation to injury to this body region. Figure 15 shows the static intrusion associated with the different levels of ankle/foot injury.

Most of the cases (90%) with slight or no injury had low intrusion levels (0-5cm). By comparison, most of the cases with AIS 2+ injury showed intrusion greater than 5cm. It should be noted however that 45% of drivers with AIS 2+ ankle/foot injury had experienced intrusion of only 0-5 cm.

DISCUSSION

This study has examined the relationship between the EuroNCAP ratings for body region protection and compared those ratings to actual injury outcome in real frontal crashes. In addition, the opportunity was taken to examine the kinds of frontal crash and types of occupant associated with serious injury in modern cars. In effect, to explore the ways in which the consumer test programme might be further developed.

In the sample of 653 crashes studied, the AIS 3+ head injury rate was just 1%, compared to a 4% rate for the chest. The
upper leg AIS 2+ rate was 6%, the lower leg AIS 2+ rate was less than 1% and the AIS 2+ rate for the ankle/foot was 6%. This indicates that, in modern vehicles, protection for the head is good, which agrees with previous research (Lenard et al, 1998; Frampton et al, 2000; Frampton et al, 2002; Kirk et al, 2002) Regarding life threatening injury, chest protection should take the priority. In terms of injuries which cause impairment, protection for the upper leg and ankle/foot should be considered. By comparison, lower leg protection appears to be good in this sample of crashes.

The EuroNCAP head protection ratings were difficult to assess against serious head injury in real crashes. Partly because there were few serious injuries to consider and partly due to the kinds of crashes which caused those injuries. However, in this sample, there were virtually no cars with a head protection rating lower than “marginal” and this may reflect the very low injury risk in the real-world crashes. Of the 8 cases available, one was a severe impact (ETS 89 km/h) and three were impacts with heavy trucks where injury occurred from head impact to the truck. In the remaining 4 cases, injury was caused by head impact with an intruding A-pillar. Two of those cars were classed as “adequate” for head protection, one as “good” and one as “marginal”. It is extremely difficult to get a good head injury score in the EuroNCAP frontal test without an airbag. EuroNCAP has encouraged the fitment of airbags and as such, it has been extremely successful in reducing the risk of injury to the head.

Chest protection scores for EuroNCAP did not show a clear trend with the occurrence of AIS 3+ injury in the real crashes. Even though the groups of real crashes were comparable for crash severity, overlap and driver age. A study of the factors related to serious chest injury showed a mean ETS of 41 km/h with more than half of the injuries occurring in full overlap configurations. Driver age was considered as a confounding factor, however the mean age for the drivers with AIS 3+ chest injury was only 46 years. It should be noted that a good rating in a single point offset test does not guarantee performance in higher overlap impacts where frame stiffness issues may be more apparent. This may be a possible explanation for the issues here, especially as half of the serious chest injuries were caused by seat belt webbing loads. Crash research shows that the chest protection in modern cars is still little different to that in older vehicles (Frampton et al, 2000, 2002) and perhaps there is scope now to consider a test of the restraint system.

Cars representing all levels of EuroNCAP upper leg protection were represented in the real-world crash injury sample. At the extremes of protection (“poor” and “good”) the EuroNCAP rating system showed a trend toward representing the
real-world risk of AIS 2+ injury. The situation for the “weak”, “marginal” and “adequate” categories was less clear even though the real crash groups were comparable for crash severity and front overlap. The mean ETS for AIS 2+ upper leg injuries was 45 km/h, almost half occurring with full overlap. The mean age for drivers with these injuries was 40 years. It is perhaps surprising that these injuries occur with full overlap crashes in cars which have been encouraged to reduce intrusion in a high speed offset test. Additionally, it is worthy to note that nearly 40% of drivers with these injuries experienced facia intrusion less than 6 cm. However, a high proportion of drivers sustaining these injuries were females (62%). As females are generally shorter than males, they sit closer to the front interior structures. This suggests there is scope for injury assessment based on a 5th percentile female dummy placed in an appropriate seating attitude.

Cars representing all levels of EuroNCAP lower leg protection were represented in the real-world crash injury sample. Even though there were only 8 cases with AIS 2+ lower leg injury, 5 were contained in the cars classed as “poor” and “weak” by EuroNCAP, one in the “marginal” group and two in the “adequate” group. There was an under-representation of these injuries in cars classed as “marginal” and none in the cars classed as “good”. The rating system therefore appears to show some reflection of the real-world risk. This is especially reinforced by the low rate of these injuries overall. Injury sources for the lower leg included the pedals, facia, footwell and 3 drivers with injury from bracketry under the steering column cladding. All of these are assessed by EuroNCAP modifiers except for the steering column. This could be usefully added in the assessment.

Cars representing all levels of EuroNCAP ankle/foot protection were represented in the real-world crash injury sample. The samples were comparable for crash severity and front overlap. Those cars classed as “poor” and “weak” by EuroNCAP showed an over-representation of AIS 2+ ankle/foot injuries, while those classed as “marginal”, “adequate” and “good” showed an under-representation. This suggests that the rating system for injury risk has a relationship to real drivers in real crashes. The mean ETS for AIS 2+ ankle/foot injuries was 39 km/h, 50% occurring with full overlap. The mean age for drivers with these injuries was 42 years. As with upper leg injuries, it is surprising that these injuries occur with full overlap crashes, 45% of occupants with those injuries experiencing less than 6cm of footwell intrusion. Nevertheless, Crandall et al (1995) have already shown from crash tests that loading of the lower extremity can be higher in cars with lower levels of intrusion. As with AIS 2+ upper leg injury, a high proportion of drivers sustaining AIS 2+ ankle/foot injuries were females (61%). Despite the reasonable prediction of ankle/foot injury by the
EuroNCAP rating system, this study suggests that the addition of a small female dummy may be appropriate. Additionally, although ankle/foot injury sources have not been explored here, previous work by Thomas and Bradford (1995) provided a case for assessment of injury potential when the dummy’s right foot is placed on the brake pedal.

Lie (2000) suggested that there was a good correlation between the overall EuroNCAP star rating and real crash performance. That study did not specifically examine the scoring by body region and was not able to examine the situation for injuries classed as “serious” because of their impairing as opposed to threat to life value. This paper has examined those specifics and found that the body region scoring system reflects trends in real crash injury risks to all body regions, except for the chest. More generally, further development in the assessment could concentrate on a restraint system test and the use of smaller dummies seated appropriately, rather than an increase of the test speed.

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www.euroncap.com

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Further information on CCIS can be found at http://www.ukccis.org