Predicting vehicle performance under the Global Technical Regulation on Pedestrian Protection using ANCAP test results

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Abstract

Selected new vehicles are tested by the Australasian New Car Assessment Program (ANCAP) to assess their level of pedestrian protection. The draft Global Technical Regulation (GTR) on pedestrian protection specifies a minimum level of protection that must be met in order for a vehicle design to be approved by regulatory bodies. This GTR may be adopted as an Australian Design Rule under a 1998 UNECE agreement. One possible implication of this is that many vehicles may require significant redesign in order to meet the GTR requirements. The GTR testing protocol is similar to the ANCAP tests, but differs in some respects. The individual impact tests are conducted under less severe conditions: the impact speed is lower, the child headform mass is higher, and the adult headform mass is slightly lower. This paper examines three new vehicles, and assesses their likelihood of meeting the requirements of the GTR, based on their ANCAP test results. A method for scaling the Head Injury Criterion (HIC) for different masses and velocities is used to predict GTR performance from a corresponding ANCAP test result. Among the vehicles considered, the areas tested would produce a significantly lower HIC by the GTR test method than by the ANCAP test method. However, on other vehicles there are many locations that were assessed as poor by ANCAP, which are likely to require redesign in order to meet the requirements of the GTR.

Keywords

Pedestrian, Vehicle Safety, Impact Testing, Regulations

Background

Vehicles can be designed to reduce the incidence and severity of injuries to a struck pedestrian, in the same way that they can be designed for the safety of their occupants.

For the last 10 years, the Australasian New Car Assessment Program (ANCAP) has tested and assessed selected new vehicles for pedestrian safety, and assigned them a star rating. ANCAP assesses vehicles using the Euro NCAP pedestrian testing protocol [1]. The testing protocol specifies four different dummy impactors that are projected into different locations on the vehicle. A full-leg impactor is used on the bumper, an upper leg impactor on the leading edge of the bonnet and child and adult headform impactors are used on the bonnet top and windscreen areas. Each impactor is fitted with sensors that are used to gauge the severity of the impact. This testing has taken place at the Centre for Automotive Safety Research impact laboratory in Adelaide, and has included the assessment of over 100 vehicles to date.

In recent years, regulations have come into place in Europe and Japan that require all new vehicle designs to be tested for pedestrian safety [2]. Additionally, the Working Group on Passive Safety under the United Nations Economic Commission for Europe (UNECE) have drafted a Global Technical Regulation (GTR) on pedestrian protection [3]. The GTR differs from the Phase 1 regulations already in place in Europe and from those in Japan. Australia is a signatory to the UNECE 1998 Agreement on Global Technical Regulations [4] and it is likely that the GTR on pedestrian protection will be adopted as an Australian Design Rule under this agreement. If this occurs, then all new vehicle designs sold in Australia will have to be tested under the GTR protocol, and comply with its requirements.

The ANCAP and GTR test protocols

Thus, there are two pedestrian testing protocols which are relevant to Australia – the Euro NCAP testing protocol used by ANCAP, and the GTR testing protocol. In the case of the full leg tests, the ANCAP and GTR protocols are almost identical; however the GTR does not include an upper leg test. Both protocols require headform tests, which involve firing an instrumented headform into specific locations on the vehicle front surface. Depending on the wrap around distance to each location, either a 'child' or 'adult' headform is used. The wrap around distance, commonly abbreviated as WAD, is the distance measured to a test location from the ground at the front of the vehicle along the vehicle surface.

The acceleration of the headform is measured during the impact and is used to calculate the Head Injury Criterion (HIC), a number which represents the relative risk of head injury. The equation for calculating HIC is derived from the Wayne-State tolerance curve for head impacts [5], and is based on the premise that the risk of head injury increases with the duration and magnitude of the acceleration experienced by the head. A HIC of 1000 is commonly used as an acceptable limit.

There are differences in the specifications and requirements of the tests under each protocol. These differences are summarised in Table 1, and are explained in further detail below.

Table 1: Summary of differences between ANCAP and the GTR

Parameter	ANCAP	GTR
Test speed	40 km/h	35 km/h
Child headform mass	2.5 kg	3.5 kg
Adult headform mass	4.8 kg	4.5 kg
Child test area	WAD 1000 – 1500 mm	WAD 1000 – 1700 mm
Adult test area	WAD 1500 – 2100 mm (may include windscreen)	WAD 1700 – 2100 mm (excludes windscreen)
HIC requirements	HIC < 1000 scores maximum points HIC > 1350 scores zero points 1000 < HIC < 1350 marginal	HIC < 1000 to pass anywhere HIC < 1700 to pass in 'relaxation' zone

For ANCAP testing, the child and adult test areas are each split into 6 numbered zones across the width of the test area. Each zone is then split into 4 smaller subzones, lettered A to D (see Figure 1). Within each zone, ANCAP selects what is thought to be the most potentially harmful test location. The vehicle manufacturer is then given the option to nominate one or more of the subzones in each zone for an additional test. ANCAP then selects the worst location in the nominated subzones. For example – if the most harmful location is chosen in subzone A, the manufacturer might choose subzones C and D for an additional test. The most harmful location might then be chosen in subzone C for the additional test.

Each zone is worth a maximum of 2 points, which contribute towards the star rating of the vehicle. If the manufacturer does not nominate an additional test, then the original test location counts for the maximum 2 points. Otherwise, the 2 points available are shared between the two test locations depending on how many subzones the manufacturer has nominated. For example – if they have only nominated one subzone, then the manufacturer's test location count for a maximum of 0.5 points, and the original for a maximum of 1.5. If the HIC at the test location is less than 1000, then the maximum points are gained for that location. If the HIC exceeds 1350, then zero points are gained. If the HIC is between 1000 and 1350 then the points score is linearly scaled – e.g. for a HIC of 1175, half of the maximum points are gained.

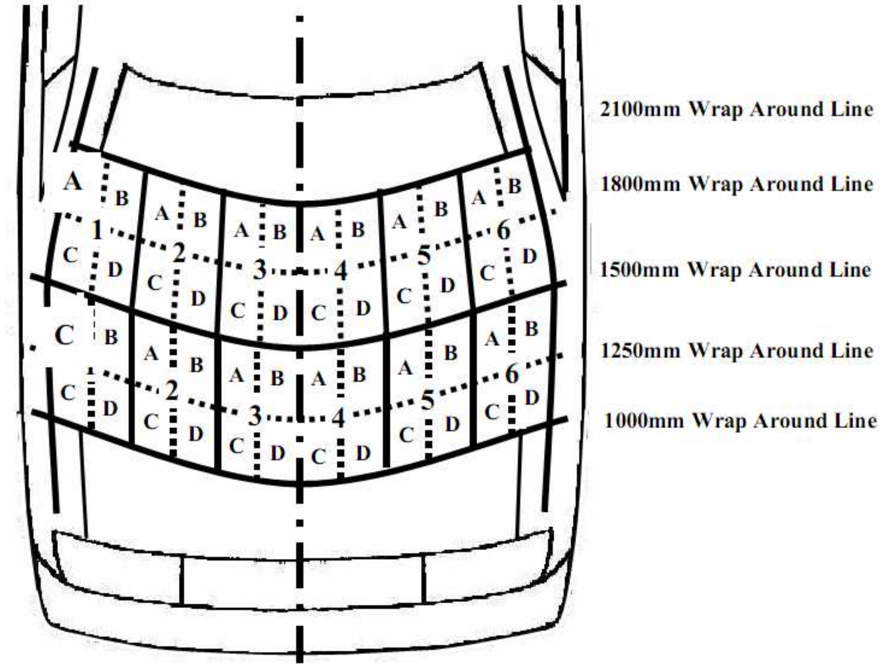


Figure 1: ANCAP zone divisions [1]

For GTR testing, the child and adult test areas are each split into thirds across the width of the test area. A minimum of nine child and nine adult test locations are chosen, with at least three test locations in each of the divided thirds. Each location is meant to be chosen on a different type of structure, and additional locations may be tested if the test house deems it necessary. The dividing line between the child and adult test areas is 200mm further up the bonnet in the GTR that it is under ANCAP, so some locations that would be tested with an adult headform under ANCAP would be tested with a child headform under the GTR. Additionally, the GTR excludes the windscreen from any testing – the headform test area is bounded at the rear by the rear edge of the bonnet (or the WAD 2100mm line, whichever comes first, which is practice in most likely to be the rear edge of the bonnet).

Any test location that results in a HIC of less than 1000 passes the GTR. However, the manufacturer can also nominate a ‘relaxation’ zone. The relaxation zone can include any parts of the test area and does not need to be continuous, as shown in Figure 2. The relaxation zone cannot consist of more than 1/3 of the total test area, and no more than 1/2 of the child test area. Any locations chosen within the relaxation zone can have a HIC of over 1000 but less than 1700 and still pass. If any test location exceeds the required HIC of 1000, or 1700 in the relaxation zone, then the vehicle fails the requirements of the GTR.

It will be important to understand the relationship between the results of the two assessment protocols. Any given test location could potentially be tested with alternate combinations of headform mass and impact speed. If a predictable relationship exists, the many ANCAP assessments can be used to estimate whether current and previous models of vehicles are likely to comply with the requirements of the GTR, and if they do not, in what respect vehicle designs will have to change to accommodate the GTR. For ANCAP, it will be important to examine whether or not the EuroNCAP protocol has important points of difference with the GTR, and what effects any future harmonisation between the two protocols may have on the results of an ANCAP assessment.

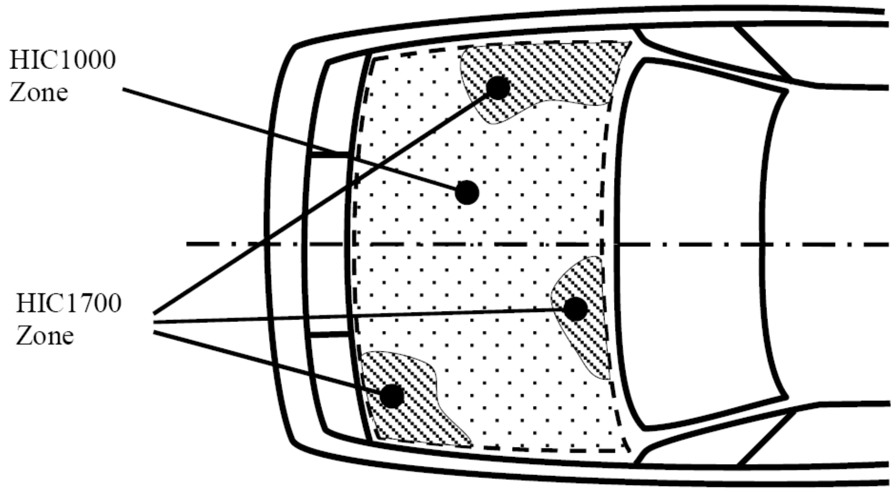


Figure 2: Example of the GTR relaxation zone [3]

Aim

This paper examines three new vehicles in detail, and assesses their likelihood of meeting the head testing requirements of the GTR, based on their ANCAP test results. The purpose of this is to give some insight into what effect the GTR might have on current vehicle designs, and on the relationship between the results of the two testing protocols.

Method

The ANCAP test results for three high selling vehicles were examined to estimate whether they would pass the GTR on pedestrian protection.

As the test conditions for the GTR are different to the test conditions for ANCAP, a method of scaling the HIC between the two sets of test conditions was required. For each test location, the HIC from the ANCAP test was scaled to what might be expected if the same test location was tested under the GTR. The scaling method is described below.

The 'relaxation' zone included in the GTR was also considered. Any test locations that were estimated to exceed a HIC of 1000 were assumed to be part of the relaxation zone, and the area that they might represent was derived by looking at areas of the bonnet surface containing similar structures. This is also discussed further below.

Method for scaling HIC

In Searson & Anderson [6] a method for modelling the effect of mass and speed in headform impact tests was presented. This method used a contact model to estimate the force experienced by a headform during an impact. The contact model was a 'damped Hertz' model, which combined a simple elastic Hertz model with a damping component. The contact model also included a separate unloading component to account for plastic deformation.

The model in [6] was used to generate acceleration data by specifying a set of contact parameters, and the test conditions. The contact parameters were four constants labelled K, n, c and J. The test conditions were the mass of the headform and the impact velocity. Given these values, a set of acceleration data could be generated, from which a HIC value was calculated. By keeping the contact parameters constant and varying the test conditions, it was possible to simulate multiple impacts on the same 'structure' with varying mass and speed.

The results generated using the contact model in [6] implies that the HIC under the ANCAP protocol is linearly related to the HIC under the GTR protocol. This suggests that if we know the HIC from a test at a particular location, we can scale it to a HIC under some other set of test conditions, using a linear scaling factor.

This analysis was extended to find the variation, if any, in the scaling factor for a pair of test conditions. For the purposes of this study, there were three pairs of test conditions that needed to be examined. The first was comparing an ANCAP child headform test with a GTR child headform test. The second was comparing an ANCAP adult headform test with a GTR child headform test, which is important for test locations at a WAD between 1500 and 1700 mm (see Table 1). The third was comparing an ANCAP adult headform test with a GTR adult headform test.

To do this, a 'Monte Carlo' style simulation was run that did the following:

1. A random set of contact parameters *K*, *n*, *c* and *J* was selected within specified ranges. The range of values allowable for each contact parameter was derived from experience with matching the contact model to real impact data.
2. An impact pulse was generated for four different test conditions: An ANCAP child and adult headform test, and a GTR child and adult headform test.
3. The HIC was calculated for each of the four scenarios above.

The results were then compared against each other for each of the three pairs of test conditions described above. The results are shown in Figure 3, and from this we can see that the relationship between the HIC under different test conditions can be approximated by a linear relationship.

The results for each pair of test conditions are summarised below in Table 2. The impact speed for all ANCAP tests was 40 km/h, and for all GTR tests was 35 km/h.

Table 2: Scaling factors and headform masses for different wrap-around distances

	Headform type (ANCAP-GTR)		
	Child-Child	**Adult-Child**	**Adult-Adult**
WAD range (mm)	1000 – 1500	1500 – 1700	1700 – 2100
ANCAP headform mass (kg)	2.5	4.8	4.8
GTR headform mass (kg)	3.5	3.5	4.5
HIC scaling factor	**0.56**	**0.83**	**0.72**

The scaling factors listed in Table 2 can be used to scale the HIC obtained from each ANCAP location into an equivalent estimated HIC under the GTR. The scaling factor used depends upon the wrap around distance to the test location.

More generally, it was found that the scaling factor depends on a power law that takes into account the ratio of masses and ratio of impact speeds. If two impact tests were conducted, one with headform mass m_1 and impact speed v_1, and the other with headform mass m_2 and impact speed v_2, then the ratio of the HIC values obtained in each test could be found as follows:

$$\frac{HIC_1}{HIC_2} = \left(\frac{m_1}{m_2}\right)^a \left(\frac{v_1}{v_2}\right)^b \quad (1)$$

The exponents *a* and *b* in this equation were found by linearising (1) and using multiple regression on the simulation results. Equation (1) was linearised by taking the logarithm of both sides:

$$\log\left(\frac{HIC_1}{HIC_2}\right) = a\log\left(\frac{m_1}{m_2}\right) + b\log\left(\frac{v_1}{v_2}\right) \quad (2)$$

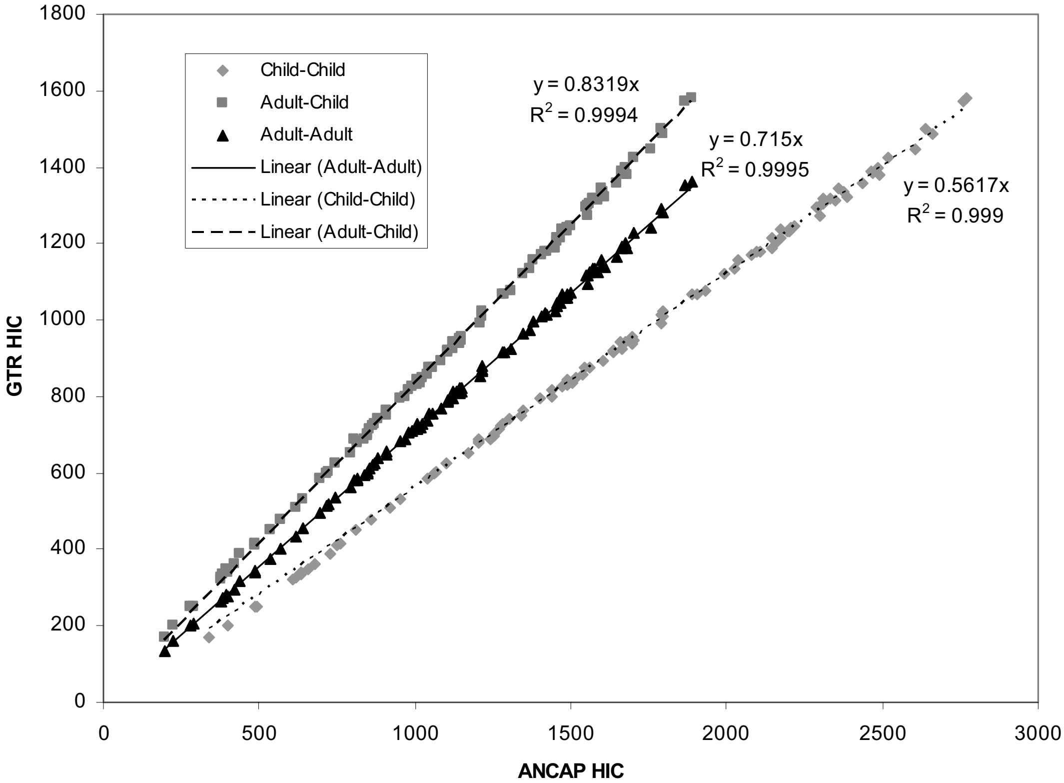


Figure 3: Comparison of HIC under different protocols from randomised simulations using a Hertz-damped contact model.

Equation (2) was used to perform multiple regression, in order to estimate *a* and *b*. The regression was performed using results from simulations using many randomised sets of contact parameters *K*, *n*, *c* and *J*. For each set of contact parameters, the impact conditions (mass and impact speed) were varied, and the HIC was calculated for each combination. The results of the regression are shown in Table 3.

Table 3: Regression results for estimating exponents *a* and *b*

Parameter	Value
a	-0.637
b	2.845
R^2	0.99

The ratio of the coefficients *a* and *b* show that, proportionally, a change in impact speed has 4.5 times the effect of an equivalent proportional change in mass.

Comparing the test areas under each protocol

Under the ANCAP testing protocol, each location is chosen within a certain well defined zone or set of subzones. Each location represents the 'worst' location within that area. Under the GTR, each location is chosen to represent one of many 'worst' locations across the entire bonnet surface. As mentioned earlier, the GTR is further differentiated by the ability of the manufacturer to choose a 'relaxation' area in which the acceptable HIC (1700) is higher than for the rest of the test area (1000).

Some locations tested by ANCAP might be expected fall within this relaxation area. For the purposes of this analysis, it was assumed that any test location which had an estimated GTR HIC of greater than 1000 would be expected to be inside the relaxation area. If a test location was inside of the relaxation area, then a reasonable estimate was made of the number of subzones represented by that test location. This took into account similar structures nearby, and the presence of any symmetrical test locations.

It was assumed that each ANCAP subzone was approximately the same size on a given vehicle. Thus, the proportion of the GTR test area represented by each ANCAP test location was calculated using the total number of subzones in the GTR test area. From this, the percentage of the GTR test area that would need to be the 'relaxation' area was estimated. This would have to be less than 33% in order for the vehicle to pass the GTR requirements.

Results

The results for each vehicle are summarised below in Table 4. The Mazda3 had a total of 40% of its test area estimated to be a part of the relaxation area. While this exceeds the maximum of 33%, it is possible that this percentage could be reduced through more careful selection of the relaxation area boundaries. None of the three vehicles had any test locations with an estimated GTR HIC in excess of 1700.

The Toyota Camry scored the highest under ANCAP, receiving 2 stars overall, and 14.5 out of 24 head test points. The Camry also had the lowest percentage of its test area estimated to be within the relaxation area out of these three vehicles. The Holden Commodore and Mazda3 scored similarly under ANCAP, but the Commodore had significantly less area estimated to be within the relaxation area than the Mazda3.

Table 4: Summary of results

Vehicle	Toyota Camry	Holden Commodore	Mazda3
ANCAP star rating	2	1	1
ANCAP head test score (out of 24)	14.5	8.98	8.15
Number of locations	9	7	10
Number of locations, GTR HIC > 1000	2	2	2
Number of locations, GTR HIC > 1700	0	0	0
% of test area estimated in relaxation area	16.7%	19.4%	40.0%

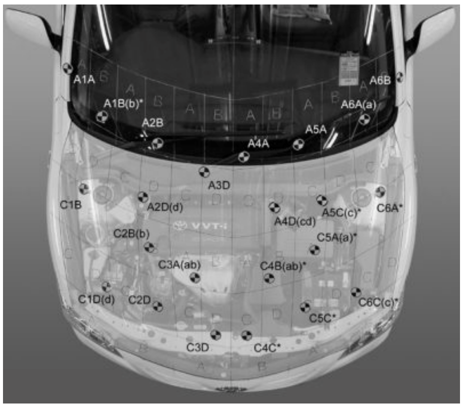
The full results for each location on each vehicle are given in Table 5. Note that the percentages of area represented by each location do not sum to 100% for each vehicle. This is because there may be portions of the test area not represented by any test location, and these were assumed to not be a part of the relaxation area.

The results in Table 5 indicate that many ANCAP locations that scored a HIC in excess of 1000 were estimated to pass the GTR. Additionally some locations that scored in excess of 1350, or zero ANCAP points, were also estimated to pass the GTR, even without being inside of the relaxation area.

While none of the three vehicles exceeded the maximum allowable GTR HIC of 1700, the scaling factors indicate that it is likely that this HIC would be exceeded on some ANCAP vehicles. A GTR HIC of 1700 corresponds to an ANCAP child head test scoring a HIC of 3036. For an ANCAP adult head test the corresponding HIC is 2048 if it corresponds to a GTR child location (WAD 1500-1700mm), or 2361 if it corresponds to a GTR adult location (WAD 1500-2100mm). Tests exceeding these values have occurred - of the last ten vehicles tested by ANCAP, five have at least one location with a HIC in excess of these values.

Note that there is an additional criterion in the GTR, which is that no more than 50% of the relaxation area may be within the child test area. This was difficult to estimate given the information available, but it would appear that none of the three vehicles would be in danger of violating this requirement.

Table 5: Results for each vehicle by test location. Locations that were estimated as inside the relaxation area are shown in italics.

Vehicle	Location	ANCAP HIC	Estimated GTR HIC	% of test area represented
Toyota Camry	*C1B*	*2615*	*1464*	*16.7*
	C1D(d)	895	501	5.6
	C2B(b)	1173	657	11.1
	C2D	1024	573	11.1
	C3A(ab)	974	545	11.1
	C3D	1015	568	11.1
	A2D(d)	1001	831	11.1
	A3D	956	688	5.6
	A4D(cd)	705	585	5.6
Holden Commodore	*C1B*	*2264*	*1268*	*16.7*
	C2A	823	461	22.2
	C3B	1339	750	11.1
	C3D(cd)	1014	568	11.1
	A2D(cd)	686	494	5.6
	A3D(cd)	781	562	11.1
	A5C(cd)	*1650*	*1188*	*2.8*
Mazda3	*A2C*	*1729*	*1435*	*20.0*
	*C6D*	*2394*	*1341*	*20.0*
	C1D(d)	1181	661	3.3
	C2D	1126	631	6.7
	C3D	1353	758	3.3
	C4C	1369	767	3.3
	C4D(abd)	757	424	20.0
	C5C(cd)	910	510	6.7
	C6C(c)	1205	675	3.3

Discussion

Pedestrian impact testing has been conducted regularly in Australia over the last decade in order to assess the performance of selected new vehicles. A new GTR on pedestrian protection is expected to be introduced in Australia in the near future, which will mean that all new vehicle models will be tested, and must meet a minimum level of pedestrian protection.

The GTR testing procedure is similar to the procedure used by ANCAP. However, in the GTR tests the impact speed is lower, the child headform mass is higher, and the adult headform mass is slightly lower. Additionally, the boundary between the adult and child test areas is different, and the base of the windscreen is excluded altogether from the GTR testable area. Finally, the HIC requirements of the GTR are different – test locations scoring a HIC of up to 1700 are allowed inside of a specified 'relaxation' area, while the remaining test locations must score a HIC of less than 1000. Under ANCAP, full points are awarded for a HIC of less than 1000, and no points are awarded if the HIC exceeds 1350.

The goal of this paper was to give some indication of how likely it is that existing vehicle models will pass the GTR on pedestrian protection, and what changes might be required. To do this, three vehicles were examined that have been previously tested by ANCAP and have high sales figures in Australia. A method of scaling the HIC values obtained during ANCAP testing has been developed, and was used to estimate equivalent HIC values if the same locations were tested under the conditions of the GTR. The ANCAP zone markings have been used to estimate what proportion of the testable area is represented by each test location. From this, the performance of each vehicle under the GTR has been estimated.

Each vehicle had 1-2 test locations that were estimated to exceed a HIC of 1000. The area representation of those locations was used to estimate the size of the required relaxation zone in order for that vehicle to pass the GTR. This was less than the required 1/3 of the testable area for two of the vehicles; however the third vehicle had a required relaxation zone size that was 40% of the testable area, though it may be possible to reduce that proportion if the relaxation zone was selected more carefully, without using the predefined ANCAP zone markings. None of the vehicles examined had a test location that was estimated to exceed the maximum allowable HIC of 1700 under the GTR, although it would appear that many other vehicles tested by ANCAP would fail this requirement.

Thus, on a location-by-location basis, it would appear that the GTR leads to significantly reduced HIC values. When the entire vehicle is considered, the results also suggest that the GTR might be significantly easier to perform well in than ANCAP tests – a vehicle that scored 1 star only under ANCAP was estimated to pass the head testing requirements of the GTR.

A more general relationship between HIC and mass and speed is given in Equation 1. The values of a and b given in Table 3 imply that the HIC is more sensitive to changes in impact speed than changes in mass. If the headform mass was constant between the two protocols, the change in speed alone from 40 km/h to 35 km/h would lead to HIC values under the GTR of around 68% of the ANCAP equivalent. Similarly, the biggest potential change in mass, from 2.5 kg to 3.5 kg, leads to a GTR HIC of about 81% of the ANCAP equivalent.

The ANCAP and the GTR testing protocols serve different purposes. ANCAP exists to evaluate the relative performance of a vehicle, and the GTR will ensure a minimum level of performance for all vehicles. Because of these different purposes, it might be expected that the GTR will have more relaxed requirements than the ANCAP procedure. It is possible though, that the GTR requirements are sufficiently relaxed that very little will need to be changed in current vehicle designs. The one benefit of the GTR may be that extremely dangerous locations that exist on some vehicles will have to be redesigned.

One limitation of this analysis is that only the locations tested under ANCAP could be examined. On each vehicle, there may be additional test locations which would exceed the maximum allowable HIC under the GTR. Another potential limitation is that the method of scaling the HIC was based on simulated data, and may require further real test data for validation. To address both of these limitations, each of these three vehicles is being tested according to the GTR protocol. If the scaling methods presented in this paper are validated by these tests, then the methods described herein may be used to examine the GTR performance of more than 100 vehicles tested by ANCAP to date.

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