HOW USEFUL ARE THE TWO CHILD DUMMIES IN THE REAR SEAT OF NCAP TESTING?

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Paper Number 11-0134

ABSTRACT

This study aimed to investigate the utility of the responses of the two child dummies (P1.5 and P3) that are placed in the rear seat, in identical forward-facing child restraints during frontal Australian NCAP (ANCAP) tests.

Dynamic responses of the two child dummies, vehicle crash parameters, and frontal dummy responses were extracted from the ANCAP report database for 35 frontal crash tests. Linear regression analysis was used to assess: the similarity between the two dummies' responses; variation between frontal dummy responses; and relationships between the child dummy responses and other measured crash parameters.

Dynamic responses from the P1.5 and P3 dummies were highly correlated with each other, including head accelerations, neck forces, and chest accelerations ($p<0.0001$ for all, $0.4 < R^2 < 0.6$). Variation between the two rear-seated child dummies was substantially less than between the driver and front passenger dummies. The child dummies' head and chest accelerations were correlated to vehicle b-pillar deceleration ($p\leq0.01$ for all), but not to vehicle mass, vehicle class, or other crash parameters ($p>0.05$ for all).

Unlike the two front-seated occupants, where the dummies provide different information about the vehicle's safety performance, the two rear-seated child dummies in child restraints are providing essentially duplicate information. Head excursion of the dummies is not measured in the current ANCAP test protocol, and this may be a more sensitive and meaningful assessment of child restraint occupant serious head injury risk. Only 35 vehicles were included in the analysis, and data on some variables (including neck moments, and harness and top tether payout during testing) were not recorded in all tests.

These results suggest that using two child dummies in forward-facing child restraints is not providing significantly more information than could be gleaned from a single child dummy in a forward-facing child restraint. This suggests that one of these child dummies could be usefully replaced with an alternative dummy representing an older rear seat occupant, without loss of information on a vehicle's ability to protect child-restraint users. Possibilities for such a replacement occupant include a 10 year old child dummy using the lap-sash seatbelt (as is being trialed in Japan NCAP tests), a booster-seated 6 year old dummy, or a small female occupant. Any of these options would provide additional information on vehicle safety performance than is currently being reported in most NCAPs.

INTRODUCTION

While the majority of vehicle design and regulation has focused on front seat occupants, a number of recent studies have indicated that the protection provided to rear seat occupants is declining relative to the front seat (Esfahani and Digges, 2009, Kent et al., 2007, Bilston et al., 2010). However, this interest in rear seat occupant protection has not translated into consumer crash testing programs or regulations around the world.

The effectiveness of existing protective systems for rear seat occupants such as seat belts is influenced by occupant anthropometry. Huang and Reed (2006) analysed the National Automotive Sampling System General Estimates System (NASS-GES) for the years 1999-2002, and found that approximately 50% of rear seat occupants in that sample were over 12 years old and 30% over 18 years of age. Bilston and Sagar (2007) used data from the 2005 US National Occupant Protection Use Survey (NOPUS) and reported that occupants over 16 years of age made up approximately 33% of all rear seat occupants.

A rise in the number and type of safety systems available to front seat occupants has been observed since the mid 1990's (Beck et al., 2009). Apart from the inclusion of lap-shoulder belts in all seating positions in most new model vehicles and the presence of rear curtain airbags, little else has changed for the rear seat occupant. This means that front seat occupant protection has improved more than for rear seat occupants. Studies have suggested that the front seat is now substantially safer than

the rear seat for older adult occupants (Esfahani and Digges, 2009, Kuppa et al., 2005). This was supported by a matched-cohort analysis of belted front and rear seat occupants that suggested that the front seat is now safer than the rear seat for occupants over the age of 15 (Bilston et al., 2010). The latter study also reported that the benefit of rear seating for children aged 9-15 years has decreased over time.

Consumer tests such as the New Car Assessment Program (NCAP) exist to assess the protection available to front seat occupants, with improvements reflected as increasing performance scores over time (NHTSA, 2009). The first NCAP to provide consumers with vehicle safety ratings began in 1979 in the USA, and there are now similar programs run in 6 regions including North America, Europe, Australasia, Japan, Korea and China.
The Australasian New Car Assessment Program (ANCAP), based on the US testing program, was initiated in 1992. Then in 1999, ANCAP harmonized with EuroNCAP. Occupant protection is assessed through a number of crash tests, including a 64km/hr (40mph) offset frontal impact, a 50km/hr (30mph) side impact and a 29km/hr (18mph) pole impact. However, there remain several differences between ANCAP and EuroNCAP, including that while ANCAP includes two child dummies (P1.5 and P3) in forward-facing child restraints for the offset and side impact tests, no performance requirements exist for these dummies in the scoring. This is due to the differences observed between the two test programs for both child restraint design and tether locations, and also concern among Australian experts about the validity of the EuroNCAP child injury assessment criteria (Paine and Griffiths, 2002). In Australia, there is a separate consumer rating program for child restraints known as CREP (Brown et al., 2007), which is based on sled tests and therefore does not assess vehicle performance.

The Japanese New Car Assessment Program (JNCAP) began including the Hybrid III 5th percentile adult female (5th%F) in the rear seat in in 2009. The Hybrid III 5th%F is also used in the rear seat of both the full-frontal impact test and the offset frontal impact test as part of the Chinese New Car Assessment Program (C-NCAP). Mizuno et al. (2007) reported on full-width rigid barrier tests using the Hybrid III 5th%F and the Hybrid III 3 year-old (3YO) restrained in a child restraint in the rear seat. Time-history curves of chest and head accelerations showed good differentiation between the two dummies. NHTSA has also conducted tests using adult dummies in the rear seat of full frontal rigid barrier impacts for research purposes. The tests used the Hybrid III 50th percentile adult male (50th%M), Hybrid III 5th%F both restrained in lap/shoulder belts, and the Hybrid III 6 year-old (6YO) restrained in a booster seat. The rear seat dummies recorded higher head, neck and chest injury values than the front seat occupants (Kuppa et al., 2005). Another study involved the Hybrid III 10 year-old (10YO) in the rear seat of 28 NCAP tests with rear seat dummies showing higher head injury values than those in the front seat (Hong et al., 2008). Transport Canada conducted a study into rear seat occupant protection in full frontal rigid barrier tests and frontal offset tests using the Hybrid III 5th%F, Hybrid III 10YO and Hybrid III 6YO. Chest deflection, 3 msec chest clip and both lap and shoulder belt loads measured in the rear seat dummies were consistently higher than those in the front seat, with all but one test showing penetration of the lap belt into the dummy abdomen (Tylko and Dalmotas, 2005).

In this study, we hypothesized that the two child dummies used in the rear seat of ANCAP (and EuroNCAP) tests are not providing independent information on vehicle performance. If this is the case, it suggests one of these child dummies could usefully be replaced with an older dummy (e.g. 5th percentile adult female or 10 year old child) in the rear seat. This would allow more complete assessment of the rear seat safety systems.

METHODS

In the ANCAP offset frontal impact, vehicles are tested with two adult crash test dummies in the front seat and two child dummies in the rear seat. The child dummies used are the TNO P1.5 and P3, representing children aged 18 months and 3 years old. The P3 is seated behind the driver while the P1.5 is seated behind the front passenger, with the dummies in identical forward-facing child restraints. The same model restraint is used in each test.

Dynamic responses (head accelerations, HIC 36, chest accelerations, axial neck forces) of the two child dummies, vehicle and crash parameters (vehicle type, vehicle mass, b-pillar acceleration), and front seat dummy responses (head accelerations, HIC 15, HIC 36 and chest accelerations) were extracted from the ANCAP report database for 35 offset frontal impact tests (SUVs, passenger cars, people movers). Linear regression analysis was used to assess: the correlation between the two child dummies' responses; correlation between the driver and front passenger responses; and relationships between the child dummy responses and other measured crash parameters.

RESULTS

Comparisons were made between the output of both the P3 dummy and P1.5 dummy seated in the rear in identical child restraints. The head injury criterion measure (HIC36) showed significant correlation between the child dummies ($p<0.0001$). This was also observed for head acceleration in the Z direction (vertical from the crown of the head) and resultant head and chest accelerations ($p<0.0001$ for all) (see Table 1).

Table 1.
Correlation between rear seat P1.5 and P3 dummy measurements

Variable	P-value	R^2
HIC36	<0.0001	0.51
Head Acceleration Z	<0.0001	0.45
3ms Resultant Head Acceleration	<0.0001	0.47
3ms Resultant Chest Acceleration	<0.0001	0.48

A similar analysis was conducted for the dummies seated in the front seat – a Hybrid III 50th% adult male in both the driver and passenger position. Unlike the child dummies, the recorded values from front seat dummies showed no significant correlation. The linear regression results are shown in Table 2.

Table 2.
Correlation between driver and front passenger Hybrid III 50th percentile male dummy measurements

Variable	P-value	R^2
HIC36	0.26	0.039
3ms Resultant Head Acceleration	0.49	0.014
3ms Resultant Chest Acceleration	0.26	0.039

Figure 1 and Figure 2 show comparisons of HIC36 for the child dummies seated in the rear seat and the adult dummies seated in the front seat. Cases were ranked in order of increasing crash severity as measured by the B-pillar acceleration. The comparison of HIC36 for the P1.5 and P3 dummies showed good correlation (as per Table 1) with $R^2=0.51$. This in contrast to that shown in Figure 2 where the adult dummies in the front seat showed little correlation to each other ($R^2=0.040$). It is observed that there is only a small change in the passenger HIC36 for large changes in driver HIC36.

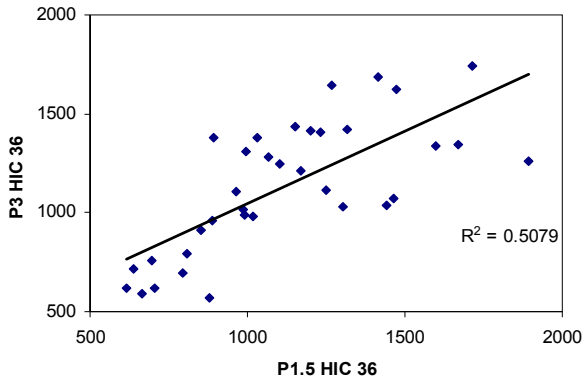

Figure 1. Comparison of HIC36 for P1.5 and P3 child dummies

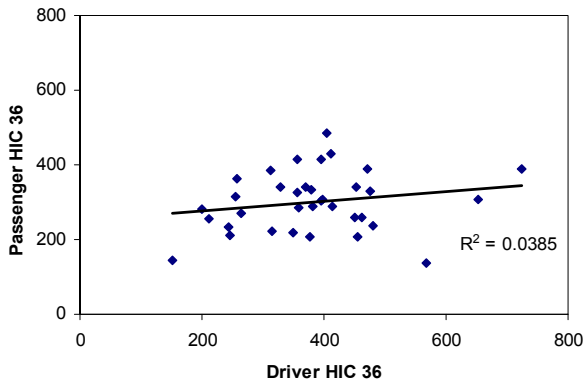

Figure 2. Comparison of HIC36 for driver and passenger dummies

Individual dummy measurements were then correlated with crash variables.
Measurements from the rear seat dummies showed no significant correlation to vehicle type or vehicle mass ($p>0.05$ for all, p-values and correlation coefficients are shown in Table 3).
There were significant correlations between b-pillar acceleration and HIC36, peak head accelerations and chest accelerations for both dummies, although the correlation was marginal for the P3 HIC 36 (see Table 3). The neck forces were not significantly related to b-pillar acceleration.

Table 3. Correlations between individual dummy measurements and crash variables.

P3								
Variable	HIC36		Peak Head Accel		Chest Accel		Fz	
	p-value	corr. coefft	p-value	corr. coefft	p-value	corr. coefft	p-value	corr. coefft
B Pillar Acceleration	0.052	0.109	0.008	0.2	0.003	0.237	0.268	0.037
Vehicle Type	0.256	0.036	0.077	0.083	0.069	0.083	0.895	0.001
Vehicle Mass	0.308	0.029	0.981	0	0.681	0.004	0.177	0.056

P1.5								
Variable	HIC36		Peak Head Accel		Chest Accel		Fz	
	p-value	corr. coefft	p-value	corr. coefft	p-value	corr. coefft	p-value	corr. coefft
B Pillar Acceleration	0.013	0.181	0.024	0.151	0.008	0.205	0.518	0.013
Vehicle Type	0.612	0.007	0.984	0.000	0.553	0.009	0.907	0.000
Vehicle Mass	0.942	0.000	0.564	0.009	0.560	0.009	0.366	0.026

DISCUSSION

The key finding in this study is that the child dummies in the rear seat of ANCAP frontal offset tests have highly correlated dynamic responses. There is also a strong relationship between the child dummy responses and the b-pillar accelerations, but no relationship to vehicle type or mass. These results indicate that, unlike the driver and passenger responses, the two child dummies do not provide independent information about vehicle safety performance. Furthermore, the child dummies largely reflect the transmitted vehicle acceleration, rather than providing detailed information about occupant protection offered by the vehicle.

The correlations between the two child dummies in forward-facing child restraints (R^2 values of 0.45-0.51 for all measurements) indicate that the results from one dummy can account for approximately 70% of the variance in the other dummy. This is in contrast to the variation observed between the driver and front passenger adult dummies where there was no correlation. Since the two child dummies in child restraints are providing essentially duplicate information, if ANCAP were to replace one of these child dummies, critical information about the performance of child restraints in the vehicle would not be lost.

North American vehicle occupancy data has shown a wide distribution of rear seat occupant age, with approximately a third being 18 years or older (Huang and Reed, 2006). These numbers indicate a wide variation in rear seat occupant anthropometry and hence the need to assess the safety provided to rear seat occupants beyond forward-facing child restraint occupants, as currently done by EuroNCAP.

JNCAP, NHTSA, Transport Canada and others have experimented with various dummies in the rear seat of full-scale vehicle crash tests. Comparisons between front and rear seat dummy Injury Assessment Reference Values (IARV) showed significantly higher values for rear seat dummies (Hong et al., 2008, Tylko and Dalmotas, 2005). In those studies however, comparisons between rear seat dummies (where applicable) were not made. Kuppa et al. (2005) reported on normalized injury values for rear outboard and center seating positions, but no significant differences between seating positions were observed. The results presented in this study showing significant correlations between rear seat dummy measurements and B-pillar acceleration are supported by Morgan (2003) who reported on child dummy measurements and child restraint performance in NCAP tests. That study showed significant correlation between the Hybrid III 3 year-old chest acceleration and the peak acceleration of the vehicle. This is not particularly surprising since IARVs should increase with crash severity. However, the relatively small amount of variance observed between vehicles tested in offset frontal impacts suggests that for child restraint occupants, the vehicle design itself is mostly affecting injury outcomes by altering the acceleration transmitted to the rear of the vehicle (as measured at the b-pillar). This is a reflection of the structural design of the front end of the vehicle (at least for frontal crashes studied here). Therefore, both this study and the Morgan (2003) study suggest that the two child dummies in child restraints are providing only modest additional

performance information over and above the b-pillar acceleration.

The introduction of an older rear seat occupant, such as the Hybrid III 10 year-old or Hybrid III 5th percentile female would make minimal difference to the cost of NCAP tests, but would provide additional information on vehicle safety performance to that currently being reported in most NCAPs. Restrained older rear seat occupants have been shown to have no effect on front seat dummy measurements (Mizuno et al., 2007). The results from this study suggest that ANCAP might gain more vehicle performance information at a similar test cost if one of the child dummies in a child restraint was replaced with an older dummy in a lap-sash seat belt.

Limitations of this study include that only 35 vehicles were included in the analysis, and data on some variables (including neck moments, and harness and restraint top tether payout during testing) were not recorded in all tests, precluding their inclusion in the regression models. Head excursion of the dummies is not measured in the current ANCAP testing protocol, and this may be a more sensitive and meaningful assessment of serious head injury risk in child occupants.

CONCLUSION

The results from this study indicate that, unlike the two front seat occupants, where the dummies provide independent information about the vehicle's safety performance, the two rear seat child dummies in child restraints are not providing significantly more information than could be gleaned from a single child dummy in a forward-facing restraint. This provides scope to include an older adult occupant in the rear seat of NCAP frontal crash testing to provide additional information on vehicle safety performance.

ACKNOWLEDGEMENTS

This study was funded by an ARC Linkage grant with partner funding from the NSW Centre for Road Safety, RTA. Lynne E. Bilston is supported by an NHMRC senior research fellowship. Julie Brown is supported by an Australian Research Council APDI Fellowship. The authors would also like to thank the ANCAP technical committee for access to the ANCAP data.

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