CONSUMER RATING AND ASSESSMENT OF SAFETY HELMETS FOR MOTORCYCLISTS

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ABSTRACT

Consumer focussed product safety evaluation programs can complement safety standards regimes and provide comparative safety performance information that influences purchasing decisions as well as driving improvements in safety performance. A Consumer Rating and Assessment of Safety Helmets (CRASH) program was developed for the Australian motorcycle helmet market. The objective of this paper is to report on the assessment and rating program and results for 2011-12 helmets.

A protocol was developed to assess AS/NZS 1698 certified motorcycle helmets by crash protection and ergonomics. Dynamic crash protection tests included: 2.5 m and 0.8 m impact energy attenuation tests onto a flat anvil; 2.5 m impact energy attenuation test onto a kerb anvil; dynamic strength of the retention system; and dynamic stability. A rating system was developed using, for example, published head acceleration tolerance data with a maximum score given for the 2.5 m tests when the peak headform acceleration was ≤ 150g and none if > 250 g. Other dynamic tests were similarly rated. Usability tests included: in-helmet noise, drag forces and ventilation recorded in a wind tunnel on a KEMAR acoustic mannequin at 100 km/h; visor splash and fog resistance; and ease of use.

In 2011-12 61 helmets were assessed, the lowest aggregate crash protection score was 21% for an open face helmet and the highest was 74% for a full-face helmet. The lowest aggregate usability score was 32% and the highest 75%. There was no correlation between crash and usability scores, although a few helmets scored highly in both areas. There was a correlation between scores for high and low energy tests onto the flat anvil (r=0.799). There was a negative non-significant correlation between helmet mass and average peak acceleration (g) for all three tests, r=-0.546, r=-0.414 and r=-0.204, high energy flat anvil, low energy flat anvil and high energy kerb anvil, respectively. The "A" weighted equivalent sound pressure level (Leq_A) was derived from wind tunnel tests. The minimum was 95 dB and the maximum 110 dB, with an average of 101 dB, demonstrating large differences in noise generation between helmets. For the eight 2011 CRASH helmets that had been assessed in the SHARP program, there was a modest correlation between the aggregate crash protection score and SHARP star rating (r=0.681).

The testing identified differences between helmets largely specific to each test, inferring that each test examined a unique performance aspect. Where possible scores were based on published human tolerance data, including noise, or derived from other standards. In some cases, tolerance data were extrapolated to suit the range of results obtained from the helmet tests, because reference data were not available. An oblique impact test is being considered for inclusion in the CRASH program.

The CRASH program provides motorcycle helmet performance and usability information that can assist motorcyclists in purchasing decisions. Further research and development is required to optimise the testing, scoring and rating system of the program, and the communication of results.

INTRODUCTION

Consumer focussed product safety evaluation programs can complement safety standards regimes and provide comparative safety performance information that influences purchasing decisions as well as driving improvements in safety performance, eg. New Car Assessment Programs. The CRASH program was developed for the Australian motorcycle helmet market.

Motorcycle ownership and usage in Australia has increased greatly in recent years. Between 2006 and 2011 the number of motorcycles registered in

Australia rose from 463,057 to 678,790, an overall increase of 48.5%. During a similar period, 2006 to 2010, the total distance travelled by motorcyclists rose from 1,641 to 2,394 million kilometres, an overall increase of 45.9% [1]. Although deaths as a proportion of registered motorcycles has steadily decreased from 2002 (6.04 per 10,000) to 2011 (2.96 per 10,000), the absolute number of annual Australian motorcyclist fatalities has fluctuated around 215 ± 25 between the years 2002 and 2011, and in 2011 comprised 15.6% of road user fatalities (201/1291) [2]. In addition to fatal injuries, there are hospitalised motorcyclists who may have a range of head injuries from concussion to diffuse axonal injury [3,4]. The 2011 IRTAD report provides a snapshot of the incidence of fatalities by road user groups across 32 countries and shows similar global trends [5]. Therefore, providing motorcyclists with information to assist in the purchase of the safest helmets represents one component of the safe systems approach to reducing motorcycle related trauma.

Research on the helmet performance characteristics that contribute to motorcyclist safety demonstrated the importance of: Crash protection (impact performance, head coverage, chin-bar, dynamic stability) and Ergonomic factors (usability, noise, fog resistance, ventilation, mass, aerodynamics, visibility and weather resistance). For example, Richter et al indicated that misuse of the helmet retention system and failures of the retention system were factors resulting in the loss of a helmet [6]. The authors also compared the head impact speed and impact location to ECE 22-4 in some cases. They observed that 90% of the impacts were below the ECE 22 test line. Such factors could be addressed through usability tests, head coverage, dynamic stability and dynamic retention strength. Although, Liu et al noted that there was "insufficient evidence to demonstrate whether differences in helmet type confer more or less advantage in injury reduction" in their 2004 meta-analysis of motorcycle helmet effectiveness studies; a methodological issue recognised by others [7,8]. Therefore, a program was developed to measure a range of motorcycle helmet safety and ergonomic characteristics on an annual representative selection of motorcycle helmets. Inputs into the development of the program included focus group meetings with motorcyclists, expert opinion and analysis.

For the helmet impact tests, head acceleration limits were derived for concussion, skull fracture and brain injury [9-13]. The boundaries for maximum and no score were based on, respectively, a 20% and 40% risk of fracture and AIS 3/4 head injury. After adjustment for the use of rigid headforms, the approximate 20% and 40% risk thresholds for fracture and AIS 3/4 head injury were 150 g and 250 g. For concussion, the limits were set between 80 g (≈60% risk) and 120 g (≈95% risk).

The objective of this paper is to report on the CRASH motorcycle assessment and rating program and the results for 2011-12 helmets. At the time of writing this paper, an embargo on the publication of individual make/model test results exists for 2012 helmets.

METHODS

Assessment and testing

The test protocols were developed using existing standards (UN/ECE 22, DOT 571.218, SNELL M2010 and AS/NZS 1698) as guidance, or adapted from standard protocols used in related fields (e.g. sound pressure level (SPL) measurement, aerodynamic loads and ventilation). Only one impact per helmet and test site was undertaken. The following tests were undertaken (Tables 1 and 2).

Table 1.
Description of crash protection test methods

Conditions	Measured
<u>Helmet Coverage</u> The amount of inner liner which extends outside the test line at the front, sides and rear is measured	Length (mm)
<u>Chin Coverage</u> Visual inspection	Presence of chin bar
Dynamic Stability AS/NZS 2512:2009 Section 7.2	Angle of rotation of helmet
<u>High Level Energy Attenuation</u> 2.5 m drop onto flat anvil as per AS/NZS 1698. Six impacts.	Peak centre of mass headform acceleration (g) and rebound height (mm)
<u>Low Level Energy Attenuation</u> 0.8 m drop onto flat anvil as per AS/NZS 1698. Six impacts.	as above
<u>Kerb Anvil Energy Attenuation</u> 2.5 m drop onto curb anvil as per AS/NZS 1698. Four impacts.	as above
<u>Dynamic Retention Strength</u> ECE 22.05 Section 7.6	Residual displacement (mm)

Scoring and Rating

After testing all measures were applied to a set of scoring criteria. Individual scores were summed to obtain a total score (Tables 3 and 4). Helmets were assigned stars for both safety and ergonomics according to the following criteria: Score < 30% 1 Star; 30 ≤ Score < 50% 2 stars; 50% ≤ Score < 70% 3 stars; 70% ≤ Score < 85% 4 stars; and, Score ≥ 85% 5 stars.

Table 2.
Description of ergonomic test methods

Conditions	Measured
Operation and fit (i) Standard protocol with ten questions and (ii) in-situ force to commence helmet displacement measured.	(i) Five point Lickert scale (ii) Forwards, Rearwards and Lateral Force (N)
Visor's ability to resist fog up BS EN 166:2002	Time until fogging (seconds)
Ability to seal out weather (splash) Adapted from AS 1337.1:2010 – Eye protectors for industrial applications, Method for the Determination of Splash Resistance	Proportion of unstained surface area.
Wind tunnel tests: SPL and Aerodynamic loads. KEMAR acoustic mannequin mounted in wind tunnel. Wind speed = 100 km/h. Measurements of SPL, ventilation and aerodynamic loads made: face-on with vents open and closed and at 45 degrees with vents open. Furness FC0510 micro manometer measured the pressure difference between a reference and pressure tapping points on (a) the tip of the nose and (b) the crown.	(i) SPL in Leq dB (A) (ii) Aerodynamic loads, Anterior-posterior and vertical forces (N) and bending moment (Nm) (iii) Ventilation pressure (Pa)
Mass Weighed on calibrated scales	Mass (kg)
Field of view UN/ECE 22	Distance (mm)

Helmets

All helmets in the sample were at the time certified to AS/NZS 1698. The helmet sample was derived from advice from wholesalers, retailers and consumers, as well as historical trends and coverage of specific categories of helmets: open face, open face + visor, full face, motocross, flip-up (Figures 1 to 6).

Testing

All tests derived from standards tests methods were performed at laboratories certified to undertake those tests. Aerodynamic and SPL tests were performed in a university operated wind tunnel (Figure 7). The National Acoustics Laboratories performed SPL measurements. The same six individuals performed operation and fit assessments in each year. Each person had an ISO "J" equivalent sized head and all tests were conducted with suitably sized helmets.

Figure 1. Exemplar full-face helmet

Figure 2. Exemplar flip-up helmet

Figure 3. Exemplar motocross helmet

Figure 4. Exemplar open-face helmet

Figure 5. Exemplar open-face + visor helmet

Figure 6. Exemplar dual sport helmet

Table 3.
Scoring and weighting criteria for crash protection criteria. Where otherwise not stated the score was calculated using a linear interpolation between the upper and lower criteria

Crash Protection	Criteria
Helmet Coverage	Max = 5%. Coverage < 225 mm = 0%. Coverage ≥ 307 mm = 5%
Chin Coverage	Chin bar present = 5%. No chin bar = 0%
Dynamic Stability	Max = 10%. Angle of Rotation ≤ 10° = 10% and > 30° =0%.
High Level Energy Attenuation	Max = 30% Score: Headform Acceleration (g) ≤150 = 25% and > 250 = 0%. Standard Deviation: If acc < 200, and SD < 10 g, then SD=0=5% & SD=10=0%
Low Level Energy Attenuation	Max = 15% Score: Headform Acceleration (g) ≤80 = 10% and >120 g = 0% Standard Deviation: a/a
Kerb Anvil Energy Attenuation	Max = 25% Score : Headform Acceleration (g) ≤150 = 20% and > 250 = 0% Standard Deviation: a/a
Impact Energy Rebound	Max = 5% Score: Coefficient of restitution ≤ 0.2 = 5% and > 0.3 = 0%
Dynamic Retention Strength	Max = 5% Score: Dynamic elongation (mm) ≤ 25 mm = 5% and > 40 = 0%

Figure 7. KEMAR acoustic mannequin mounted in wind tunnel.

Analyses

For the purposes of this report data have been de-identified. Descriptive statistics and correlations between performance measures are presented. All analyses were conducted using SPSS™ version 20.

RESULTS

In 2011 31 helmets were included in the program. In 2012 a further 30 helmets were included. A descriptive summary of the impact test results is presented in Table 5. The average peak headform acceleration for the 2.5 m flat anvil drops ranged from 146 g to 265 g; median 186 g. The average peak headform acceleration for the 0.8 m flat anvil drops ranged from 79 g to 132 g; median 99 g. Mean standard deviations for the three impact test types were in the range 6 g to 14 g. This indicates that helmet performance was relatively consistent for each test type. The mass range for the helmets was 0.957 kg to 1.957 kg with a median of 1.61 kg.

A descriptive summary of item and total safety scores for all 61 helmets is presented in Table 6. The median safety score was 59 (three stars) with a range from 21 (one star) to 76 (four stars). Helmets performed best against the following criteria: coverage, and both high impact energy tests and standard deviations. Helmets performed worst against the following criteria: low impact energy, dynamic strength of the retention system and rebound (coefficient of restitution).

Table 4.
Scoring and weighting criteria for ergonomic criteria. Where otherwise not stated the score was calculated using a linear interpolation between the upper and lower criteria.

Ergonomics	Criteria
Operation and fit	Max 20%. Summed and average of responses.
Visor's ability to resist fog up	Pass = 20%. Fail= 0%
Ability to seal out weather (splash)	Max 5%. Proportional to surface area unstained.
Noise inside the helmet	Max 20%. SPL (dB) ≤ 90 = 20% and > 110 = 0%.
Ventilation	Max 15%. Score=0.1 average pressure difference
Aero-dynamic neck loading	Max 10%. Neck force ≤ 5 N = 5% and > 43.5 N = 0%. Neck moment ≤ 0.435 Nm = 5% and > 2.175 Nm = 0%
Mass	Max 5%. Mass ≤ 1kg = 5% and > 2 kg = 0%
Peripheral view	Max 5%. Mid sagittal aperture measured. 5% > 20 mm.

Table 5.
Summary of impact test results (n=61 helmet models)

	Median	Mean	SD	Min	Max
High Impact Energy - Average Peak Acc. (g)	186	188	22	146	265
High Impact Energy - Standard Deviation (g)	10	14	9	1	37
Low Impact Energy - Average Peak Acc. (g)	99	101	11	79	132
Low Impact Energy - Standard Deviation (g)	6	7	4	2	24
High Impact Energy - Kerb - Average Peak Acc. (g)	160	164	16	134	201
High Impact Energy - Kerb - Standard Deviation (g)	5	6	4	0	15
Helmet Mass (kg)	1.6	1.5	0.2	1.0	2.0

Table 7 presents correlations between the crash protection scores. A bivariate correlation was undertaken with two-tailed tests of significance. Although many of the correlations were significant, the pearson correlation statistic (r) values for the pairwise comparisons indicated generally weak to moderate correlations. The strongest correlation ($r=0.799$, $p<0.01$) was between the average peak acceleration scores for the 2.5 m flat anvil and 0.8m flat anvil impacts. There was a negative non-significant correlation between helmet mass and average peak acceleration (g) for all three tests, $r=-0.546$, $r=-0.414$ and $r=-0.204$, high energy flat anvil, low energy flat anvil and high-energy kerb anvil, respectively.

Table 6.
Summary of crash protection scores, total score and star rating (n=61)

	Median	Mean	SD	Min	Max
Coverage	9.3	7.7	3.2	0.0	10.0
Dynamic Stability	5.7	5.8	2.7	0.0	10.0
High Impact Energy - Average Peak Acc. Score	16.0	15.5	5.2	0.0	25.0
High Impact Energy - Standard Deviation Score	0.0	0.7	1.1	0.0	4.3
Low Impact Energy - Average Peak Acc. Score	5.3	4.9	2.6	0.0	10.0
Low Impact Energy - Standard Deviation Score	0.8	1.3	1.4	0.0	4.2
High Impact Energy - Kerb - Average Peak Acc. Score	17.9	17.1	2.9	9.7	20.0
High Impact Energy - Kerb - Standard Deviation Score	2.5	2.2	1.5	0.0	4.8
Coefficient of Restitution	0.4	0.8	1.0	0.0	3.9
Dynamic Strength	1.2	1.2	1.1	0.0	4.5
Total Score (%)	59.0	56.9	13.0	21.0	76.0
Star Rating	3.0	2.9	0.7	1.0	4.0

Table 7.
Correlations between crash protection scores. Pearson correlation statistic presented in cell.
*** p<0.05; ** p<0.01**

	A	B	C	D	E
(A) High Impact Energy - Average Peak Acc. Score					
(B) High Impact Energy - SD Score	.265*				
(C) Low Impact Energy - Average Peak Acc. Score	.799**	.314*			
(D) Low Impact Energy - SD Score	.614**	.268*	.684**		
(E) High Impact Energy - Kerb - Average Peak Acc. Score	.589**	.350**	.555**	.301*	
(F) High Impact Energy - Kerb - SD Score	0.055	0.004	0.158	0.183	0.246

Table 8 presents a descriptive summary of the individual and total ergonomic scores, plus the star rating. The median safety score was 52 (three stars) with a range from 32 (two star) to 77 (four stars). Helmets performed best against the following criteria: splash resistant (Figure 8), neck loads and ventilation. Helmets performed worst against the following criteria: resistance to fogging and noise.

In absolute terms the in-helmet noise measured in the wind tunnel at 100 km/h was high. The median weighted average of the three conditions was 100 dB, with a range from 95 dB to 110 dB.

Figure 8. Post Splash testing of helmet.

Table 8.
Summary of ergonomic test scores, final score and star rating (n=61)

	Median	Mean	SD	Min	Max
Helmet Fit and Operation Score	12.5	12.4	1.6	8.8	15.1
Splash Score	5.0	3.9	1.7	0.0	5.0
Fog Score	0.0	5.9	9.2	0.0	20.0
Noise Score	10.0	9.2	3.7	0.0	15.0
Ventilation Score	9.9	10.2	3.4	3.1	15.0
Neck Force Score	3.7	3.6	0.6	1.3	4.6
Neck Moment Score	3.3	3.0	1.5	0.0	5.0
Helmet Mass Score	3.0	3.4	2.0	0.2	9.6
Peripheral View Score	3.4	3.2	1.8	0.0	5.0
Ergonomic Total Score	52.0	54.6	11.0	32.0	77.0
Ergonomic Star Rating	3.0	2.7	0.7	2.0	4.0
Summary SPL (dB)	100.0	100.8	3.7	95.0	110.0

Correlations between the individual ergonomic scores were generally weak to moderate (Table 9). The correlation between the total safety scores and total ergonomic scores was weak and not significant (r=0.252).

DISCUSSION

The results of an extensive battery of performance tests on 61 motorcycle helmets are presented. All helmets were certified to AS/NZS 1698: 2006, which includes a resistance to penetration test. It was challenging to obtain reliable information on compliance of each helmet to other standards, although SNELL certification is routinely attached where appropriate in the Australian market. For the eight 2011 CRASH helmets that had been assessed in the United Kingdom's SHARP program, there was a modest correlation between the aggregate crash protection score and SHARP star rating (r=0.681). Therefore, the CRASH program and SHARP differ in some regards.

Table 9.
Correlations between ergonomic test scores. Pearson correlation statistic presented in cell. * p<0.05; ** p<0.01

	A	B	C	D	E
(A) Helmet Fit and Operat-ion Score					
(B) Fog Score	-0.07				
(C) Splash Score	.456**	-0.25			
(D) Noise Score	.270*	-0.02	0.17		
(E) Ventilat-ion Score	0.11	0.09	0.10	-0.01	
(F) Neck Force Score	0.18	0.17	0.13	.317*	0.19

The weak to medium level of correlation between individual scores provide some support for the value in undertaking the wide range of tests. This suggests that each test is a measure of a unique characteristic. In addition each test was included because it was considered to be an important factor in crash protection performance and ergonomics. Both areas are considered to contribute to overall levels of safety. In the longer term, feedback from motorcyclists will assist in understanding how useful each test it in terms of influencing purchasing decisions. Brand related responses to the CRASH program through performance improvements might also be a barometer of the weighting helmet manufacturers place on the program and specific elements.

The high correlation between headform accelerations for the high impact energy and low impact energy flat anvil impacts indicates the potential for manufacturers to produce helmets that perform equally well across a range of impact severities. This information is valuable for consumers as it indicates that a 'safe' helmet need not necessarily be tuned to a specific type of use – commuter or touring, freeway commuting or inner city commuting. This is also valuable contribution to discussions regarding helmet standards, where there has often been comment on the need for more compliant foams to accommodate low severity impacts. No strong correlations were observed between ergonomic and crash protection scores. This suggests that there are opportunities for manufacturers to improve the helmets in areas that benefit the public and improve the CRASH performance. Although not proven by these tests, they indicate that a manufacturer could helmet ergonomics that might improve the experience of wearing a helmet without those changes necessarily reducing safety. Both safety and ergonomics could be improved.

Discussions are ongoing regarding the inclusion of an oblique impact test into the CRASH program [14,15]. Two helmets from the 2011 CRASH program were included in a series of oblique impact tests (horizontal speed 35 km/h drop height 1.5 m) [14]. The CRASH program identified the ratio of the average maximum headform acceleration in the high-energy flat anvil acceleration for the two helmets to be 1.40. Ratios for peak headform linear and angular accelerations in the oblique tests were in the range 1.4 to 1.50. At face value this provides a strong indication of consistency between the forms of assessment and might suggest that oblique impacts may not add more detail. Further research is required.

The tests conditions for the wind-tunnel tests were discussed extensively. The final test conditions were determined after consideration for budget, time, and how well the conditions represent riding conditions. The head and neck posture in these tests is upright. It is acknowledged that each motorcyclist will adopt different postures depending upon the type of motorcycle, the environment, their ability, and personal preferences. It is intended that the aerodynamic scores will provide some general guidance.

Ventilation measurements were also challenging. Other measures, e.g. heat dissipation, were considered, but were not compatible with the single test set-up for measuring SPL, aerodynamics and ventilation. Further work is required to compare the results of the testing to date with other measures of ventilation. However, the results do indicate the comparative level of airflow through the helmet.

The helmet tests highlighted the issue of in-helmet noise. The observation that the median SPL was 101 dB for an equivalent road speed of 100 km/h identifies the need to advise motorcyclists about methods to mitigate the short and long term effects of this exposure through the use of ear plugs, for example, or to advocate for 'quieter' helmets [16]. In addition to long term hearing loss, exposure to high noise levels may lead to temporary hearing impairment with safety implications for motorcyclists.

More generally, public feedback is required to ensure that the CRASH program is delivering helmet information to the public that is meaningful, both in terms of content and delivery.

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