# EVALUATION of MOTORCYCLE HELMET USABILITY and STABILITY in the CONSUMER SAFETY RATING PROGRAM 'CRASH'

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Paper Number 15-0292

## ABSTRACT

A review of certain aspects of the Consumer Rating and Assessment of Safety of Helmets (CRASH) for motorcyclists was undertaken. The paper examines the relationships between the assessment of helmet stability with volunteers and other usability assessments. The paper reports on how these assessments are incorporated into the Consumer Rating and Assessment of Safety Helmets (CRASH) and general relationships between Safety Scores and Ergonomic Scores. Ninety (90) motorcycle helmets were evaluated in the years 2011 to 2014 involving dynamic stability tests, dynamic strength of retention tests and usability tests with six participants. All helmets complied with AS/NZS 1698: 2006. The participants rated each helmet across ten items using a five point Likert scale. Forward, rearward and lateral pull tests were performed on each participant with each helmet. The force required to move the helmet with respect to the scalp was measured. The analysis revealed a number of important findings. First, safety performance tests are not correlated with ergonomic assessments of the helmets, including formal usability assessments. This observations highlights the importance of providing both safety and ergonomic information to motorcyclists. Helmet mass ranged between approximately 1 kg and 2 kg in the sample assessed. On the assumption that the total Safety Score reflects a helmet that offers greater protection in a crash, a heavier helmet within the sample assessed offers more protection to the motorcyclist. Full face helmet types also performed better on total Safety Score than the open face helmet. Full face helmets were heavier than open face styled helmets. Differences in the total Ergonomic Score by helmet type were fewer than those observed with Safety Scores. There were strong correlations between the rater responses between pairs of questions regarding comfort, fit, but not restraint adjusment. Although there is some overlap between these questions, each question appears to elicit a slightly different response across all helmet types and raters. Helmet mass is either not correlated or weak to moderately correlated with user ratings. This suggests that the raters are considering other factors, not simply mass, when rating helmet weight. The raters might be considering the mass distribution, for example. In general, helmet stability as measured quasi-statically on each rater was weakly associated with the raters' assessment of the helmet. This suggests that the motorcylist's impression of fit is not a strong indicator of helmet stability. Ease of use of operation was only weakly associated, based on these results, with the forces required to displace the helmet on the rater's head. Correlations between the stability test forces by direction (front, rear and lateral) were strong.

## INTRODUCTION

Powered two wheeler (PTW), including motorcycle, safety is a major global issue. Although the incidence rates for motorcyclist injury and death have decreased over decades, the absolute number of cases has been increasing as a result of increased motorcyclist exposure.[1] Motorcycle helmets are one method for preventing head injury in motorcycle crashes.[2,3] Geographical regions and countries have unique systems in place that regulate the supply and use of motorcycle helmets. A central element of these systems are motorcycle helmet standards. Standards are referred to with regards to both sale and on-road use. Standards are critical in terms of providing motorcyclists with effective helmets. However, Standards do not assess all aspects of helmet use or performance.[4,5] Consumer rating programs can address a range of usability and performance issues that affect motorcyclist safety.[5] The paper assists in identifying how usability assessments can be applied in consumer information programs and what factors may be important in terms of helmet stability at the point of sale.

The 2011 IRTAD report highlighted that despite reductions in mortality rates for PTW operators, the relative risk remains much greater for PTW groups than passenger car occupants; in European countries the relative rate is between 17 and 20 times in some countries.[1] In the USA motorcycle fatalities comprised 14% of the total road fatalities in 2010. [1] In other regions, PTW fatalities represent the majority of road fatalities, e.g. 71% in Cambodia and 59% in Malaysia. [1] Helmet use has been shown to be effective in preventing head injury. A 2008 Cochrane review of motorcycle helmet estimated that helmets reduce the risk of head injury by 69% and death by 42%. [2] A study of trauma centre admissions found that helmets were associated with a significant reduction in intracranial injury likelihood of 66% amongst motorcyclists.[6] Therefore, an important element of a road safety system is helmet use.[1-6]

Helmets need to fit well and be comfortable.[7] Maintaining the positional stability of a motorcycle helmet in general use and a crash is a fundamental performance requirement. [7-10] Helmet stability is assessed in many helmet standards, but ergonomic surveys of motorcyclists have shown that helmet design and the user influence helmet stability.[4,7] A survey of 216 motorcyclists found that "the size of the in-use motorcycle helmets did not correspond well to the predicted size based on head dimensions, although motorcyclists were generally satisfied with comfort and fit."[7] The forces required to displace each wearer's helmet were also observed to be low, around 25 N. [7] The paper will examine the relationships between the assessment of helmet stability with volunteers and other usability assessments. The paper will report on how these assessments are incorporated into the Consumer Rating and Assessment of Safety Helmets (CRASH) and general relationships between Safety Scores and Ergonomic Scores.

## METHODS

Ninety (90) motorcycle helmets were evaluated in the years 2011 to 2014 involving a range of tests, including formal usability tests with six participants (raters). All helmets complied with AS/NZS 1698: 2006. The helmet sample was derived from advice from wholesalers, retailers and consumers, as well as historical trends and coverage of specific categories of helmet types. Over three CRASH rating periods Dual Sport, Full Face, Flip Up, Motocross, Open Face, and Open Face with Visor helmet types have been tested.

The test program methods were reported in 2013.[5] In short the total Safety Score reflects performance on: helmet coverage; dynamic stability; high level impact energy attenuation (2.5 m drop); low level impact energy attenuation (0.8 m drop); kerb anvil high level impact energy attenuation (2.5 m drop); and dynamic retention strength. The total Ergonomic Score reflects usability rater assessment and performance on visor fogging, splash resistance, aerodynamics, in-helmet noise, mass and field of view. The rater assessment comprises (i) a standard protocol with ten questions and (ii) in-situ force to commence helmet displacement measured. All participants had a head circumference equivalent to the ISO "J" headform (57-58 cm). The participants rated each helmet across ten items using a five point Likert scale. Forward, rearward and lateral pull tests were performed on each participant with each helmet.[5] The force required to move the helmet with respect to the scalp was measured.[5,7]

The following rating questions were considered in this analysis: Question 1. Does the helmet allocated to you fit your head comfortably; Question 2 From no pain or pressure points (score 5) to very uncomfortable (score 1) please rate the helmet with reference to your face, chin and head; Question 3 Please rate the weight of the helmet in terms

of its comfort from very comfortable (5) to very uncomfortable; Question 4 Please rate the helmet in terms of comfort and fit overall from very good (5) to very poor (1); and Question 10 How easy is it to adjust and tighten the chin strap or restraint system from very easy (5) to very difficult (1). Questions 5 to 9 were not considered relevant to the assessment as they dealt with other helmet features, e.g. the visor operation. The higher the score on the Likert scale the better the rating. Data were collated and analysed using the following statistical methods. Descriptive statistics for the total Safety and Ergonomic Scores and mass were prepared. Correlations between the total scores and mass were assessed, as were differenes in the mean total scores and mass by helmet type. Bivariate correlations between rater scores (1 to 5) and helmet mass, and pull forces were assessed.

## RESULTS

Over three CRASH rating periods a total of ninety helmets were evaluated for safety and ergonomic performance. The total Safety and Ergonomic Scores and helmet masses are presented in figures 1 to 3. The helmets are de-identified. Helmets have been sorted by type (DS Dual Sport; FF Full Face; FU Flip Up; MC Motocross; OF Open Face; OFV Open Face with Visor). There were four Dual Sport helmets (4.4%), 51 Open Face (56.7%), 10 Flip Up (11.1%), 2 Motocross (2.2%), 12 Open Face (13.3%) and 11 Open Face with Visor helmets (12.2%). Table 1 presents descriptive statistics for total safety and ergonomic scores and helmet mass by helmet type. There are significant differences ($p<0.05$) in the mean helmet mass by type: DS, FF,FU and MC are heavier than OF and OFV; OFV is heavier than OF; and, FU is heavier than FF. There are significant differences ($p<0.05$) in the mean helmet total Safety Scores by type: DS, FF and FU have higher mean Safety Scores than OF. There are significant differences ($p<0.05$) in the mean helmet Ergonomic Scores by type: FF has a greater mean than OFV. Figure 4 shows that in terms of the total Safety and Ergonomic Scores, there is a strong correlation between total Safety Score ($r^2 = 0.275$) and mass and none between total Ergonomic Score and mass. Therefore, as helmet mass increases there is an increase in the safety rating as scored in the CRASH program. The analysis of total Ergonomic Score with respect to mass is confounded by the components in the total score. Total Ergonomic and Safety Scores were not correlated.

**Table 1.**
**Descriptive statistics for helmet total safety and ergonomic scores and mass by helmet type (n=90).**

| | | Count | Mean | Median | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|---|---|
| DS | Mass (kg) | 4 | 1.68 | 1.69 | 0.12 | 1.53 | 1.8 |
| | Safety | 4 | 62 | 61 | 8 | 54 | 72 |
| | Ergonomic | 4 | 54 | 53 | 10 | 44 | 68 |
| FF | Mass (kg) | 51 | 1.61 | 1.62 | 0.1 | 1.36 | 1.94 |
| | Safety | 51 | 58 | 59 | 11 | 35 | 76 |
| | Ergonomic | 51 | 57 | 55 | 10 | 43 | 77 |
| FU | Mass (kg) | 10 | 1.78 | 1.78 | 0.1 | 1.58 | 1.96 |
| | Safety | 10 | 57 | 58 | 13 | 35 | 74 |
| | Ergonomic | 10 | 49 | 49 | 8 | 32 | 62 |
| MC | Mass (kg) | 2 | 1.66 | 1.66 | 0.01 | 1.65 | 1.67 |
| | Safety | 2 | 59 | 59 | 17 | 47 | 71 |
| | Ergonomic | 2 | 44 | 44 | 2 | 42 | 45 |
| OF | Mass (kg) | 12 | 1.18 | 1.17 | 0.15 | 0.96 | 1.43 |
| | Safety | 12 | 38 | 36 | 12 | 21 | 58 |
| | Ergonomic | 12 | 50 | 49 | 8 | 37 | 62 |
| OFV | Mass (kg) | 11 | 1.34 | 1.34 | 0.11 | 1.17 | 1.51 |
| | Safety | 11 | 51 | 49 | 10 | 37 | 66 |
| | Ergonomic | 11 | 46 | 47 | 5 | 36 | 55 |

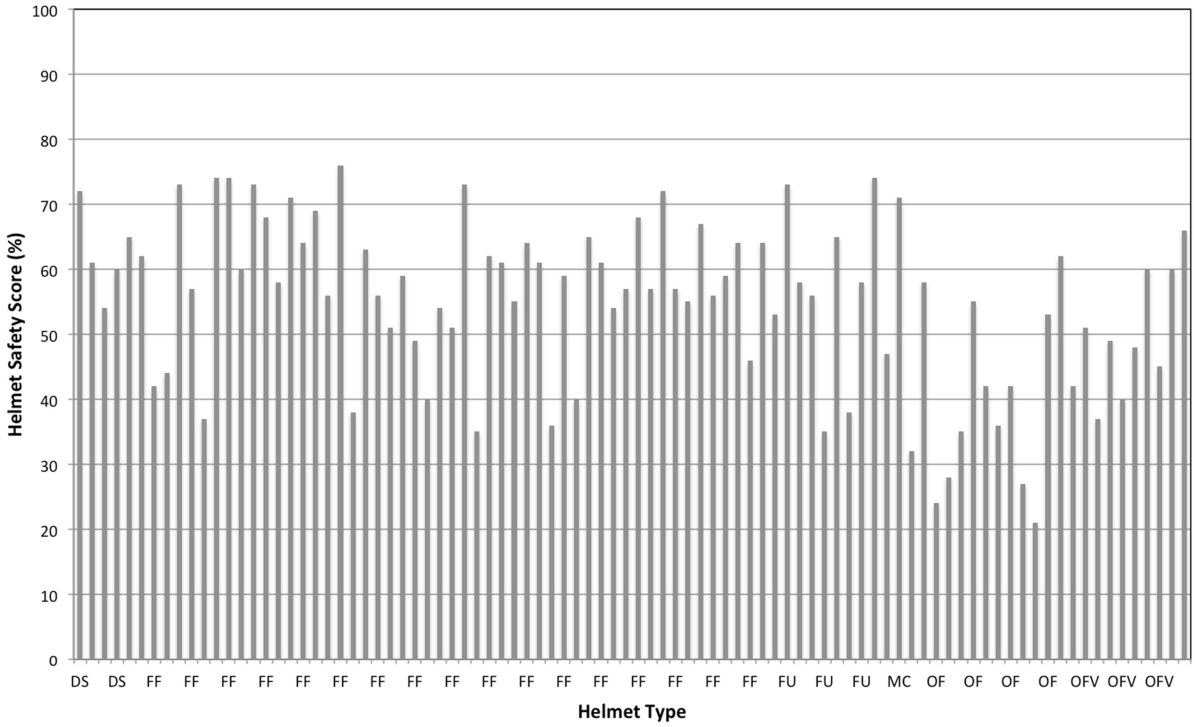


***Figure 1*. Final total safety score by helmet model grouped under type.**

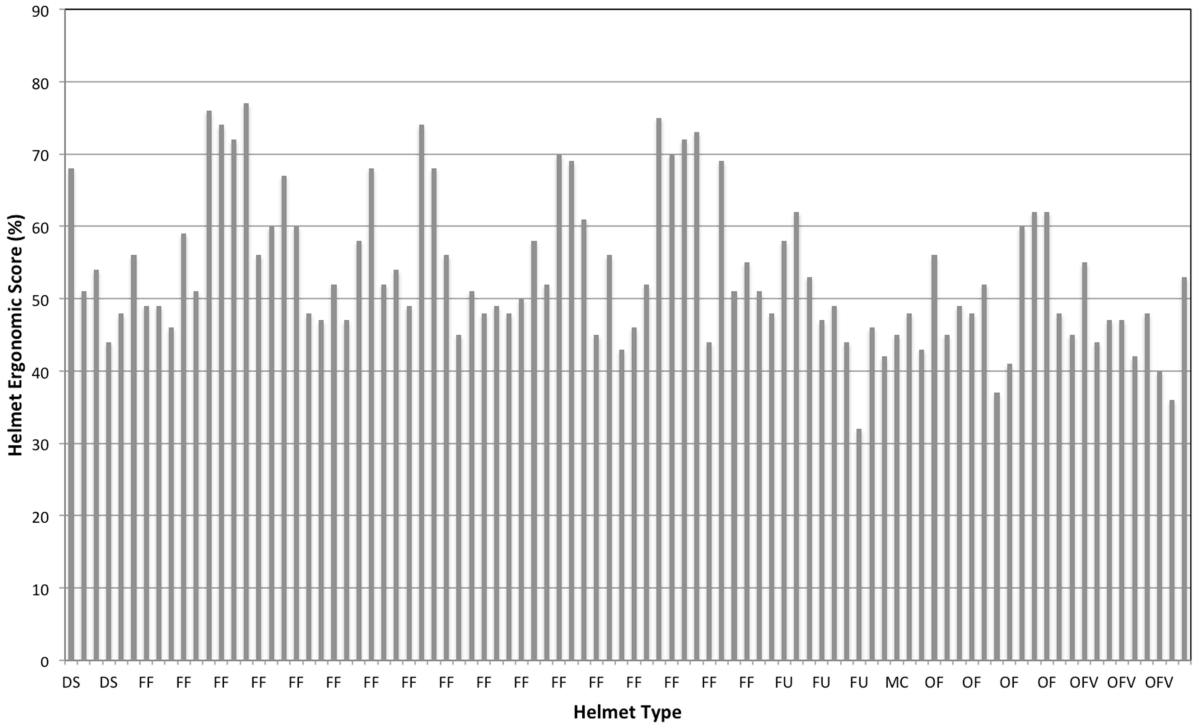


***Figure 2*. Final total ergonomic score by helmet model grouped under type.**

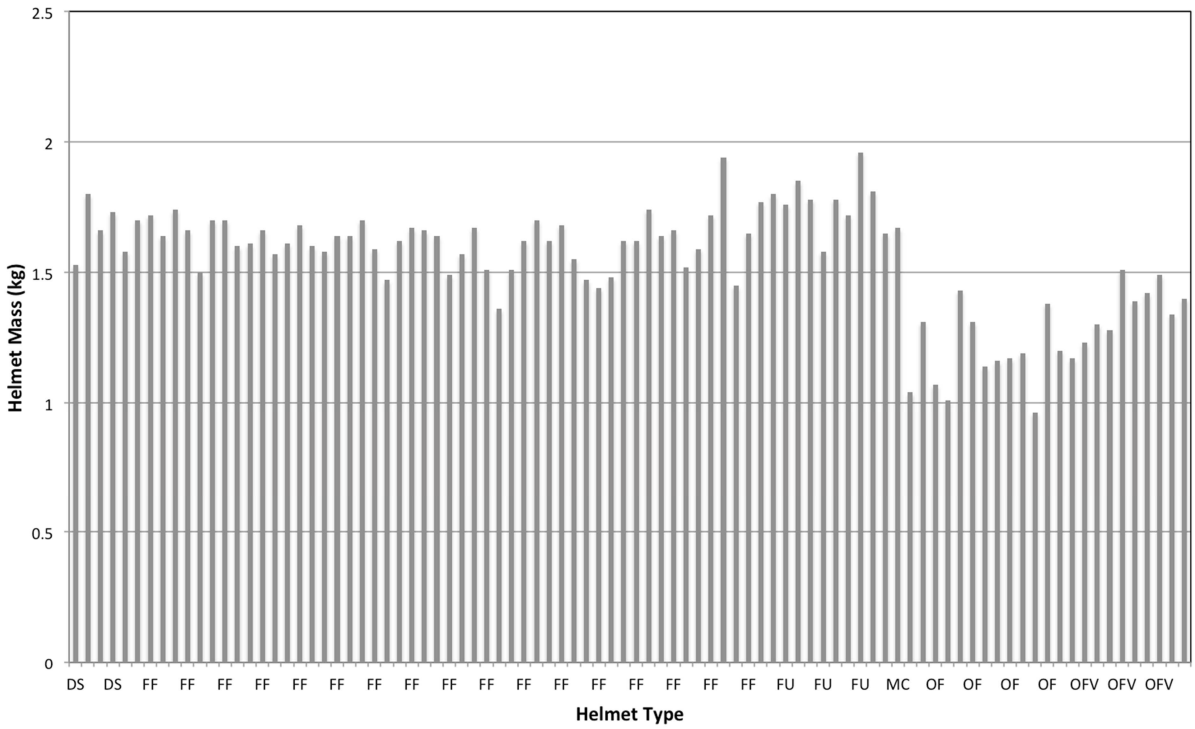


***Figure 3.*** **Helmet mass by helmet model grouped under type.**

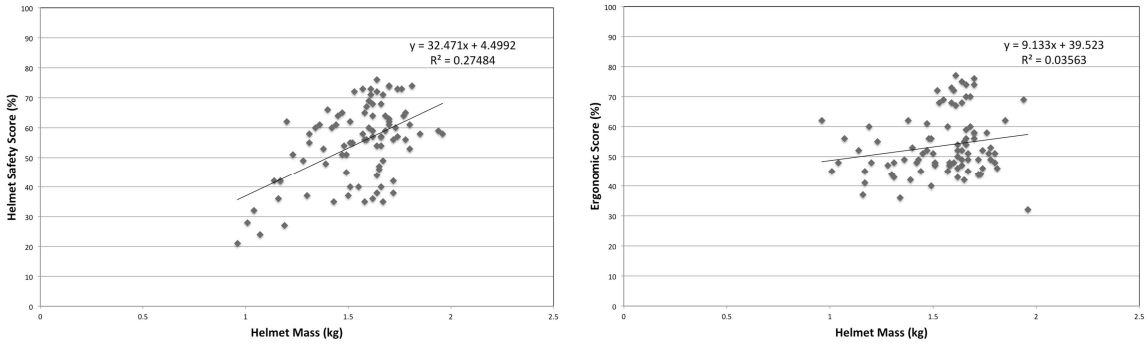


***Figure 4.*** **Helmet mass by total Safety Score (left) and Ergonomic Score (right).**

The component ergonomic scores were examined for relationships between individual ratings on specific questions, helmet mass and stability as measured quasi-statically on the rater (table 2). A number of significant correlations were observed. Analyses were not adjusted for potentially confounding factors, e.g. helmet type, rater experience and preference.

**Table 2.**
**Correlations between individual rater scores, helmet mass and forces measured in individual stability tests. The average force represents the average of three tests in each pull direction. PC is Pearson Correlation. Significance tests are two-tailed. ** Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).**

| | | Q1 | Q2 | Q3 | Q4 | Q10 | Mass (kg) | Rear (N) | For. (N) | Lat. (N) |
|---|---|---|---|---|---|---|---|---|---|---|
| Q1 | PC | 1 | .730** | .522** | .789** | .226** | -0.02 | -.172** | -.159** | -.097* |
| | Sig. | | 0 | 0 | 0 | 0 | 0.655 | 0 | 0 | 0.028 |
| | N | 509 | 509 | 509 | 509 | 509 | 509 | 509 | 509 | 509 |
| Q2 | PC | .730** | 1 | .607** | .811** | .121** | -.136** | -.208** | -.132** | -0.071 |
| | Sig. | 0 | | 0 | 0 | 0.006 | 0.002 | 0 | 0.003 | 0.11 |
| | N | 509 | 509 | 509 | 509 | 509 | 509 | 509 | 509 | 509 |
| Q3 | PC | .522** | .607** | 1 | .554** | 0.08 | -.243** | -.219** | -.206** | -.152** |
| | Sig. | 0 | 0 | | 0 | 0.072 | 0 | 0 | 0 | 0.001 |
| | N | 509 | 509 | 509 | 509 | 509 | 509 | 509 | 509 | 509 |
| Q4 | PC | .789** | .811** | .554** | 1 | .214** | -0.077 | -.155** | -.132** | -0.055 |
| | Sig. | 0 | 0 | 0 | | 0 | 0.083 | 0 | 0.003 | 0.214 |
| | N | 509 | 509 | 509 | 509 | 509 | 509 | 509 | 509 | 509 |
| Q10 | PC | .226** | .121** | 0.08 | .214** | 1 | .215** | .172** | 0.065 | .100* |
| | Sig. | 0 | 0.006 | 0.072 | 0 | | 0 | 0 | 0.144 | 0.024 |
| | N | 509 | 509 | 509 | 509 | 509 | 509 | 509 | 509 | 509 |
| Helmet Mass (kg) | PC | -0.02 | -.136** | -.243** | -0.077 | .215** | 1 | .443** | .350** | .352** |
| | Sig. | 0.655 | 0.002 | 0 | 0.083 | 0 | | 0 | 0 | 0 |
| | N | 509 | 509 | 509 | 509 | 509 | 509 | 509 | 509 | 509 |
| Average Rear Pull Force (N) | PC | -.172** | -.208** | -.219** | -.155** | .172** | .443** | 1 | .643** | .616** |
| | Sig. | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 |
| | N | 509 | 509 | 509 | 509 | 509 | 509 | 509 | 509 | 509 |
| Average Forward Pull Force (N) | PC | -.159** | -.132** | -.206** | -.132** | 0.065 | .350** | .643** | 1 | .778** |
| | Sig. | 0 | 0.003 | 0 | 0.003 | 0.144 | 0 | 0 | | 0 |
| | N | 509 | 509 | 509 | 509 | 509 | 509 | 509 | 509 | 509 |
| Average Lateral Pull Force (N) | PC | -.097* | -0.071 | -.152** | -0.055 | .100* | .352** | .616** | .778** | 1 |
| | Sig. | 0.028 | 0.11 | 0.001 | 0.214 | 0.024 | 0 | 0 | 0 | |
| | N | 509 | 509 | 509 | 509 | 509 | 509 | 509 | 509 | 509 |

## DISCUSSION

The analysis of ninety motorcycle helmets revealed a number of important findings. First, safety performance tests are not correlated with ergonomic assessments of the helmets, including formal usability assessments. This observations highlights the importance of providing both safety and ergonomic information to motorcyclists to assist in purchasing decisions that might influence long term helmet use. This underpins the rationale for the CRASH program. On one hand the helmet purchaser may select a helmet that is comfortable, for example, but this does not provide an indication of the helmet's potential safety performance in a crash. On the other hand, a focus on safety performance alone does not identify areas where improvements might be made to encourage helmet use and selection. Helmet mass was correlated with the total Safety Score. On the assumption that the total Safety Score reflects a helmet that offers greater protection in a crash, a heavier helmet within the sample assessed offers more protection to the motorcyclist. Helmet mass ranged between approximately 1 kg and 2 kg in the sample assessed. Full face helmets were heavier than open face styled helmets. Full face helmet types (DS, FU and FF) also performed better on total Safety Score than the open face helmet. Differences in the total Ergonomic Score by helmet type were fewer than those observed with Safety Scores. These analyses are very general, because they do not consider the individual elements that make up the total scores. For example, the total Ergonomic Score comprises aerodynamic and in helmet noise assessments that tend to favour full face type helmets and are less influenced by helmet mass.

The analysis of comfort and fit related usability test questions, helmet mass and user stability tests showed a number of significant correlations (table 2). There were generally strong correlations between the rater responses between pairs of questions 1, 2, 3 and 4. Correlations between questions 1 to 4 and 10 were weak. Further analyses are required to assess rater and helmet type effects on these associations. Although there is some overlap between these questions, each question appears to elicit a slightly different response across all helmet types and raters. Helmet mass is either not correlated or weak to moderately correlated with user ratings. Question 3 is a direct rating of helmet weight; there is a significant but weak association between Question 3 and measured helmet mass. This suggests that the users are considering other factors, not simply mass, in Question 3. The raters might be considering the mass distribution, for example. The experiences of each rater might also influence the assessment, e.g. a rater accustomed to wearing a 'heavy' helmet, might be comfortable with helmets in that mass range. Further analysis is required.

In general, helmet stability as measured quasi-statically on each rater was weakly associated with the raters' responses to questions 1, 2, 3, 4 and 10 (table 2). Therefore, the rater's assessment of fit and comfort are not subsitutes for stability as assessed in these tests. This requires further analysis. It does suggest that the motorcylist's impression of fit is not a strong indicator of helmet stability. Therefore, a motorcyclist might purchase a helmet based on fit that does not offer the level of stability that they expect. Question 10 relates to the operation of the restraint system. Ease of use of operation was only weakly associated, based on these results, with the forces required to displace the helmet on the rater's head.

Correlations between the stability test forces by direction were strong. Further research is required to account for potential confounding factors, e.g. helmet type and head dimensions.[7]

## CONCLUSIONS

Research has identified the importance of helmet stability and retention in terms of usability and crash performance. An analysis of the CRASH helmet data provides a greater understanding of the user's perceptions of the helmet function and what needs to be assessed in a consumer safety rating program. This information can complement impact performance and standards compliance information to assist consumer decisions and helmet suppliers in improving helmet design.

The CRASH program is funded by Transport for NSW, NRMA Motoring and Services and Transport Accident Commission (Australia).

The opinions presented in this paper are those of the authors and do not represent those of the organisations they represent.

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