Motorcycle Helmet Standards – Harmonisation and Specialisation?

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MOTORCYCLE HELMET STANDARDS – HARMONISATION AND SPECIALISATION?

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ABSTRACT

There are a number of major motorcycle helmet standards, e.g. AS/NZS 1698, DOT, JIS T 8133, Snell M2010 and UN/ECE 22. With international trade agreements, on-line purchasing, and motorcycling growth there is a need to assess whether there is scope for harmonising motorcycle helmet standards as well as specialising standards for specific environments. This paper will compare and contrast standards requirements and consider opportunities for improvements and international harmonisation.

A desktop review of standards, motorcycle helmet and relevant biomechanical literature was undertaken. The results of impact performance tests on 31 helmets that met at least AS/NZS 1698 and combinations of other standards were assessed by standard certification. Tests included 2.5m flat and hazard anvil impacts with an ISO "M" headform. Peak headform acceleration was measured. Results from oblique impact tests on motorcycle helmets were evaluated in terms of identifying the benefits of such a test. The test rig consisted of a Hybrid III head and neck falling on guided rails onto the top of a powered striker plate. Tests were conducted up to a drop height of 1.5 m and a horizontal speed of 35 km/h. Linear and angular headform acceleration were evaluated.

There are many commonalities between each standard, but there are subtle to substantial differences also. All standards have tests of acceleration management, retention system strength and stability. No standard has a true oblique impact test and chin bar assessment is varied. There are no studies that compare the performance of helmets in real world crashes by standard certification. There were few significant differences in helmet performance in lab tests by standard certification, particularly when only full-face helmets were included in the analysis. There was an overall correlation (Pearson Correlation = □0.60 (p<0.01)) between helmet mass and impact performance. Average maximum linear and angular headform accelerations for four helmets in oblique impact tests were 150g (SD=30) and 9.5rad/s^2 (SD=3.3), respectively.

Motorcycle helmets have been shown to reduce the risk of death by 42% and head injury by 69%. Mild traumatic brain injury appears to be the prevalent form of injury suffered by helmeted motorcyclists. Although there are differences between each standard, some potentially would make at best only a marginal difference in a crash. Some, such as Snell M2010 appear to be associated with heavier helmets. Oblique helmet testing can identify performance differences between helmets that are related to injury mechanisms not assessed directly by current standards. The climate and road environment are issues that need to be considered and might lead to helmet specialisation as found in JIS T 8133. In other words, operators of low powered motorcycles in hot and humid climates might have a helmet certified to a different part of a common standard compared to operators of high powered motorcycles ridden at speed on major roads. Also critical to the motorcyclists is the incorporation of a quality control system including batch testing.

These issues indicate opportunities exist for harmonisation, specialisation and improvement in motorcycle helmet standards that will benefit motorcyclists, government, trade and road safety groups.

INTRODUCTION

Ideally, the objective of a motorcycle helmet safety standard is to provide performance criteria that ensure a minimum level of head trauma reduction during a range of head impacts. Obviously this reduction in head trauma is comparative, i.e. compared to a situation had the person not worn a helmet and was subjected to the same magnitude head strike. A 'safe' helmet might thus be defined as one that provides 'significant' reduction in risk of head injury given the same impact conditions for a helmeted compared to a non-helmeted rider. However, what may be a significant reduction for one motorcycle stakeholder may not necessarily be sufficient for another, and may indeed be a hindrance to another (manufacturer/supplier), and thus may vary depending on the stakeholder; e.g. a motorcyclist, a government road safety official, a helmet manufacturer/supplier, an engineer, a trade official, etc. Those stakeholders concerned with safety would like to know how 'safe' a helmet is that meets the standard, and whether a helmet meeting one standard is 'safer' than one meeting another. Other stakeholders may see any onerous safety requirements as financially detrimental to their business, e.g. manufacturers/suppliers. Obviously there are absolute and relative comparisons that can be made.

Public confidence in any standard that specifies a particular level of safety requirement is very important. Considering that those members of the public that care about safety may not be able to assess the technical specifications of a standard, the reputation of the organisation may be the single most important factor in imparting public confidence that in the event of a crash, a helmet that meets the standard's safety performance criteria will protect a motorcyclist's head. How the standard is applied and the certification regimes are important in developing and maintaining confidence in the standard, and may be fundamental to protecting the motorcyclist's head.

One or more of the following standards govern the performance of motorcycle helmets internationally. Those standards are:

- AS/NZS 1698 Protective helmets for vehicle users (Australia and New Zealand)
- UN/ECE 22.05 Uniform provisions concerning the approval of protective helmets and of their visors for drivers and passengers of motorcycles and mopeds (Europe).
- Snell M2010: Standard for protective headgear for use with motorcycles and other motorized vehicles (USA)
- Snell 2005 Standard for protective headgear for use with motorcycles and other motorized vehicles (USA)
- USA DOT 571.218 Standard No. 218; Motorcycle helmets (USA)
- JIS T 8133 Protective helmets for motor vehicle users (Japan)
- BS 6658:1985 Specification for protective helmets for vehicle users

There is national and international interest in helmet standard comparisons, how the standards influence helmet performance and ultimately mitigate the risk of head injury for Powered Two Wheelers (PTW), i.e. motorcycle/moped riders and pillion passengers. In Australia, it has been reported that in 2008 motorcycles accounted for only 1% of vehicle-kilometres, but 15% of motor vehicle user deaths being approximately 30 times the rate for car occupants. In regards to serious injury the rate is approximately 41 times higher than for car occupants [1]. This trend for motorcyclists is counter to the falling rates of fatalities and serious injuries for other road users and similarly exists in the other countries [2]. As the international and national markets for helmets grow with increasing PTW use, and as 'on-line' retail increases, there are many reasons to review the variety of helmet standards from different countries.

METHODS

A desktop review of six motorcycle helmet standards listed above, excluding BS, was undertaken. The review covered technical aspects, epidemiological data, crash analyses and laboratory tests.

RESULTS

Impact performance

Impact performance is assessed in all the six standards using guided free fall impacts of a helmeted headform onto an anvil. Centre of Gravity (CoG) headform acceleration parameters are used to assess performance in all standards. However, there is a great deal of variation in test specifications.

<u>Test Rig and Headforms</u>

Impacts can be conducted with two-wire guided drops with a unixial accelerometer, three-wire guided drops with a triaxial accelerometer (UN/ECE 22), or with a rail mounted device and uniaxial accelerometer. There are potential differences in impact acceleration outcomes between the guided (uniaxially restrained) impacts and the unrestrained UN/ECE 22 tests.

The specific headform dimensions and sizing have not been compared, but appear similar except for the DOT standard that still mandates DOT headforms. All others mandate ISO headforms. ISO and DOT headforms are not equivalent in either mass or circumference. All impact tests utilise a rigid headform. UN/ECE 22 uses a full headform compared to the half headform used in 1698 and Snell.

<u>Test Areas</u>

In brief, the test area covers the cranium, but not the face, and is similar between standards. The "Basic Plane" is common to all as is the "Frankfurt Plane". There are some differences, e.g. the test line for AS/NZS 1698 is lower than in the Snell standards.

There is suggestion in some of the research literature that there may be an interaction between impact site and headform restraint in the specific test rig that effects headform acceleration. This is the case, for example, in the unrestrained impact when the centre of impact and centre of gravity may not be aligned.

There is an option to test over a "protective lower face cover", i.e. chin bar, in UN/ECE 22.

Flat Anvil Impacts

All standards include impacts against a flat rigid anvil of the same dimension; around 130 mm diameter. UN/ECE 22 does not require two successive impacts per impact site, unlike all other standards.

The impact velocities are different for each standard, ranging from 6m/s in 1698 to 7.75m/s in M2010. Impact energies derived for either a "J" headform of mass 4.7kg, or for DOT 5kg for the first or only impact are presented in table 1.

Table 1.
Comparative impact energies

Standard	Energy (J)
AS/NZS 1698	84.4
UN/ECE 22	132.3
M2010	141.2
M2005	150
DOT	89.8
JIS	115.3

AS/NZS 1698 has the lowest severity impact of the standards. According to Thom et al [3], the DOT flat anvil impacts, and thus AS/NZS 1698, corresponded to the 90th%ile of all motorcycle traffic crashes analysed in a 1981 report.

Other Anvil Impacts

In addition to flat anvil impacts, hemispherical, kerb or edge anvils are used in one or many of the standards. Impact against a hemispherical anvil is required in all standards, except ECE 22. ECE 22 requires impacts against a kerb anvil and M2010 and M2005 against an edge anvil. Although these impacts might introduce localised loading, only the headform acceleration is measured. Impact energies and their spread are similar to those for flat anvil impacts, although lower in both 1698 and DOT tests.

Acceleration Requirements

CoG linear headform acceleration is measured in all standards, either with a unixial accelerometer in uniaxially restrained impacts or a triaxial accelerometer in unrestrained impacts. There are potential differences in the measurements due to the different methods. Although there are minor differences, the linear acceleration requirements in five of the standards (1698, ECE, M2005, M2010 and JIS) are similar and in the range 275g to 300g. The DOT standard has a 400g requirement, which appears to be the least stringent, until the "dwell time" limit of 2.0ms at 200g is considered. ECE also has a HIC 2400 requirement. Presumably, the DOT requirements mimic the Wayne State University head impact tolerance curve [4].

There is concern that the inclusion of "dwell time limits", e.g. 2.0ms at 200g, in some standards and not others may require helmet design and construction requirements to pass more than one standard, e.g. Snell and DOT. [3,5,6] These limits are highlighted in *Figure 1*. These requirements, e.g. a stiffer shell and liner to satisfy the high energy impact requirements in Snell, may result in longer dwell times in lower severity impacts in the DOT standard and thus failures. There is also a view that in order to meet the 2.0ms 200g acceleration requirement in the DOT standard, the maximum headform acceleration will be as a rule less than 250g, in spite of the 400g limit [7,8]. It can be seen in *Figure 1* that the shapes of the permissible acceleration time histories are tightly constrained above 150g by the time constraints in 1698 and DOT standards. In contrast, the Snell and UN/ECE could expose the head to higher accelerations for longer durations.

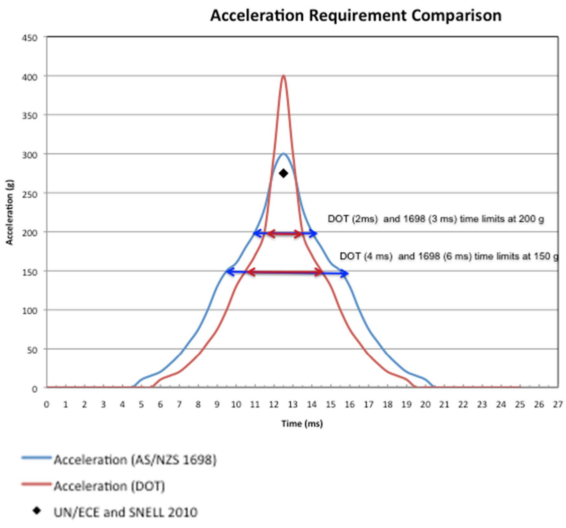

Figure 1. Schematic comparison of theoretical acceleration time histories for four standards highlighting the time limits (dwell times).

Penetration Test

All standards, except ECE 22, include a resistance to penetration test. The striker is essentially the same; 3kg with a 60° conical head, but impacts in 1698, M2005, M2010 and DOT are from 3 metres, whereas the requirement for the equivalent type 2 helmet in JIS is from 2 metres. The required outcome is the same; no contact with the headform. A rationale expressed for the penetration test is that it is a test of the integrity and build quality of the helmet. The test may fail so-called 'novelty' helmets that exist in the USA.

Chin Bar

M2005 and M2010 assess chin bar rigidity in a dynamic test. The chin bar may be assessed in ECE 22, if designated as a "protective lower face cover". It is not assessed in the other standards.

Load Distribution

There are no load distribution tests in any of the six standards. There has been no recent discussion about replacing the penetration test with a test of localised load distribution as occurred in AS/NZS 2063, bicycle helmets.

Oblique Test

Only ECE 22 (and BS 6658) has a test for projections and surface characteristics that may induce rotational forces. The other standards have an inspection regime to assess the dimensions of internal and external projections. AS/NZS 1698 has the provision to impact test internal projections greater than 2mm and oblique test for external projections greater than 5mm.

ECE 22 describes two equivalent oblique test methods. In short, a tangential load is applied to a helmeted headform by dropping it onto an inclined anvil or dragging a horizontal plate underneath the helmet. In both cases either an abrasive or a shear edge engages the helmet. The peak 'friction' force and destruction of any projections are assessed.

There is no measurement of angular acceleration or change in angular velocity in ECE 22. Therefore, the ECE 22 test is not considered by researchers to be a test of the helmet's ability to manage angular acceleration or velocity induced brain injuries [9]. The test has been criticised also because it does not replicate an impact with both tangential and radial forces; the latter causing a flattening and widening of the contact area between the helmet and the collision partner, and thus changing the tangential forces and moment.

Rigidity

Only ECE 22 has a test for transverse and longitudinal rigidity. This test may assess some properties in common with the penetration test.

Impact performance summary

On paper Snell M2010 has arguably the most stringent impact performance requirements evidenced by: the high energy input and the lowest peak acceleration output requirements; repeat impacts; penetration test; chin bar test; and, impacts against three anvils. DOT has arguably the least stringent requirements, although the effect of the acceleration dwell times may make the real peak acceleration closer to 250g. ECE 22 has a large suite of tests, some comparable to Snell M2010, and includes the only specific oblique impact test. However, the oblique test does not appear to be configured to correlate with specific angular acceleration induced injuries. ECE 22 is the only standard with transverse and longitudinal rigidity tests. These tests might evaluate some characteristics common to the penetration test. On paper AS/NZS 1698 appears to be less rigorous than ECE 22, but the repeat impact requirement in 1698 might lead to a similar level of protection in a single high energy impact for the 1698 certified helmet. Another issue to consider is the relationship between helmet mass, impact energy and the impact performance requirements in each of the standards. Whether these test requirements translate into differences in helmet performance will be examined later in the report.

Retention

The strength of the retention system is assessed in all standards. It is assessed statically in 1698, DOT and JIS through the application of a defined force and dynamically in ECE 22, M2010, M2005, and as an alternative in JIS, through a guided drop mass. ECE 22 and JIS subject the retention system to a 73.6J load and limit the dynamic displacement to 35mm, which is more than M2010 and M2005 (44.7J and 30mm maximal dynamic displacement).

Stability

Dynamic stability is assessed in all standards, except DOT. JIS and ECE 22 are the same for equivalent helmets (type 2 JIS) and require 10kg to be dropped 500mm, in comparison to only 300mm in 1698. Helmet rotation is limited to 30° in those standards. M2010 and M2005 load the helmet with a 4kg inertial hammer dropped 600mm and only require that the helmet remains on the headform.

Peripheral Vision

Peripheral vision requirements for the lateral aperture are the same on all standards, 105° on either side of the sagittal plane. 1698 and DOT do not have a requirement vertically, up and down, whereas all others are similar.

Visor

ECE 22 defines a series of optical and mechanical visor tests. M2005 and M2010 have a resistance to penetration test in which a lead pellet is fired at 500km/h at the visor. AS/NZS 1698 requires the visor to comply with AS/NZS 1609.

Batch and Continuous Control

Written into UN/ECE 22 are batch and continuous control requirements for helmets. M2005 and M2010 have random sample testing requirements conducted by Snell of helmets obtained at the point of sale. JIS and DOT do not appear to have any batch or continuous control test requirements. Batch testing requirements are being considered as part of AS/NZS 1698.

Labelling and Certification Mark

All helmet standards have some requirements for helmet labelling. These requirements include information on the helmet (make, model, month and year of manufacturer and size) as well as care and use instructions (correctly fastened, no alteration, replacement guidelines and exposure to solvents).

Helmets that are certified to Snell standards are identified by a serialised certification label. The label includes the registered trademark of the Snell Memorial Foundation (examples are found at http://www.smf.org/cert). The label can be used under licence from Snell. The JIS standard requires that the number of the standard is included in the labelling. UN/ECE requires the certified helmet be labelled with the "international approval mark". This mark comprises the letter "E" surrounded by a circle and then additional coded information on the country in which approval was granted, whether the face cover is protective and a serial number. AS/NZS 1698 requires a certification mark, where required by statutory authorities. However, AS/NZS 1698 does not describe the certification mark. The DOT standard requires that the helmet be labelled with the symbol "DOT" in one centimetre high letters on the rear external surface of the helmet.

Real world comparisons of helmet effectiveness

There is no peer reviewed published research or grey research literature that examines, using a suitable study design, whether helmets meeting one standard perform better in a crash than another. The most likely comparison would be between Snell and DOT certified helmets in the USA. However, it would be challenging to undertake such a study because the results could easily be confounded by [10,11]:

- Crash severity
- Specific characteristics of the impact
- Age of motorcyclist
- Lack of controls
- Variation in performance within helmets meeting one standard
- Helmets meeting more than one standard
- Post crash injury management
- Road rules and laws governing the sale and use of helmets in a region
- Between factor confounding, e.g. a young inexperienced rider, travelling too fast and wearing an unsuitable helmet or an older rider with a lower impact tolerance wearing a 'safer' helmet.

At a very macro-level, i.e. comparing motorcycle head injury rates in the USA between Australia and Europe, some of the same confounding factors would be present. In their 2004 meta-analysis of motorcycle helmet effectiveness studies, Liu et al [12] noted that there was "insufficient evidence to demonstrate whether differences in helmet type confer more or less advantage in injury reduction." The following summarises some recent work on this topic.

The National Highway Traffic Safety Administration (NHTSA) reported that in 2007 58% of motorcyclists wore a DOT compliant helmet, 16% wore a non-compliant helmet and 26% wore no helmet [13]. In 2009 this had changed to 67% DOT compliant, 9% non compliant and 24% no helmet [14]. NHTSA estimated that in 2008, helmets saved the lives of 1829 motorcyclists [15]. Further, that the helmets are 37% effective in preventing fatal injuries. This statement could be generalised that DOT compliant helmets are 37% effective in preventing fatal injuries. However, the lead author has noted many helmets available in Australia that signify compliance with both Snell and DOT standards, as well as AS/NZS 1698. Therefore, a proportion of the DOT compliant helmets in the USA will be compliant with Snell as well.

A retrospective case series analysis of 422 motorcycle crash victims treated at a level one trauma centre over three years in the USA showed that helmets reduced the likelihood of a traumatic brain injury by almost 50% [16]. Helmet use was not found to be associated with cervical spine fracture, although there was a small (13%) non-significant reduction in the chance of a cervical fracture for helmet wearers.

The European 'In-depth Investigation of Motorcycle Accidents' (MAIDS) concluded that a helmet was "capable of preventing or reducing the severity of head injury" in 68.7% of the 921 cases studied [17]. The analysis of the 921 cases also concluded that the PTW crash speeds were less than 50km/h in 75% of cases. Ninety-seven percent (97%) of cases sampled required at least hospitalisation, including the 11% fatalities. Therefore, the sample was biased towards the more severe spectrum of injury outcomes. There were 3417 injuries of severity greater than AIS 1 to the PTW riders and 18.4% were to the head. Around 75% of the head injuries were AIS 1 and 2 (minor and moderate). Only 90.4% of the motorcycle riders wore a helmet, despite their use being mandatory. It was observed that the helmet was ejected from the rider's head in 9.1% of cases and in the majority of cases this occurred because the helmet was not appropriately fastened.

Unfortunately, the data available from MAIDS does not facilitate a comparison with NHTSA's estimation of helmet effectiveness. An earlier 1998 study from Greece estimated that during the period 1985 and 1994, helmets reduced the risk of death for a motorcyclist by 36% [18]. They concluded that 38% of the 1994 deaths could have been avoided if the rider wore a helmet. This is the same as in the USA, however the type of helmets and the severity of crashes is not accounted for in these general figures. It could be reasonably assumed that helmet effectiveness has improved since 1994.

Research by Richter et al [19], indicated that misuse of the helmet retention system and failure of the retention system were factors resulting in the loss of a helmet. 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.

The COST project examined the performance of helmets in detail, but did not compare the performance of helmets meeting different standards [20]. A summary and interpretation of results from the COST project will be presented in the next section.

In Australia, where all helmets must be certified to AS/NZS 1698, it is challenging to compare the performance of helmets meeting different standards. Although some helmets are certified to multiple standards, it is unclear which is the most suitable for the crash that the rider experienced. Between 1999 and 2003, 53% of fatal motorcyclists were known to have worn a helmet, in an additional 13% of cases the helmet came off, and in 7% of cases a helmet was known not to have been worn [21]. In 27% of cases helmet use was unknown. Within these cases the ratio of fatal head injuries to fatal thorax injuries for helmeted motorcyclists was 32:15 compared to unhelmeted 45:7. An interesting factor regarding helmet performance requirements is the observation that "riders aged over 44 years accounted for most of the annual increase in deaths". From a helmet performance perspective, consideration for the relationship between rider age and injury tolerance may be required in helmet standards or consumer information.

Data on 220 motorcycle riders admitted to a level one trauma centre in Sydney were extracted for an 18 month period (July 2008-December 2009). 190 motorcycle riders wore a helmet. Compared to not wearing a helmet, the results showed that there was a statistically significantly lower likelihood of a helmeted motorcycle rider experiencing a head injury (Exp(B) = 0.35), intracranial injury (Exp(B) = 0.34), intracranial injury including concussion ((Exp(B) = 0.34), but not concussion (Exp(B) = 0.42) [22]. In absolute terms this shows that AS/NZS 1698 certified helmets are providing a high level of protection compared to no helmet.

In yet another study, the US Fatality Analysis Reporting System (FARS) database was queried for the years from 2000 to 2009 (inclusive), and 11,681 fatal motorcycle rural roadway departure collisions with fixed objects were identified. It was found that enforcing helmet use would provide reductions in fatality risk by around 11% [23].

To conclude, there are no suitable real world crash data that facilitate a comparison of the effectiveness of motorcycle helmets certified to specific standards in reducing head injury. Based on very limited evidence, it appears that the effectiveness of helmets in Europe and the USA in reducing fatal head injuries is similar. Finally, the data indicate the importance of the retention system, crash performance, consideration for radial and tangential impacts, the function of the chin bar, and potential biomechanical issues around the demographics of motorcyclists.

Laboratory and crash analyses of helmet efficacy

Some attempts have been made to quantify using laboratory methods performance differences between helmets certified to specific standards, and how a helmet certified to one standard might perform when tested against the requirements of another standard [7,24].

The SNELL 2005 workshop showed that the ECE 22 certified helmet deformed during the impact more than the M2000 certified helmet and the M2000 helmet had a higher maximum acceleration and HIC [24]. Tests using the M2000 impact test (J headform) against a hemispherical anvil demonstrated that the ECE helmets deformed more, but they performed especially poorly on the second impact and often worse than the M2000 certified helmet on the first impact. At that time performance differences were influenced by the headform size differences between SNELL and UN/ECE standards. SNELL and other motorcycle helmet standards in contrast to UN/ECE 22 have a double impact to the same location. The purpose of this was identified; whether this may be a more appropriate substitute for a single higher energy test, rather than an expectation that two impacts might occur in a real crash.

Thom undertook comparative testing of motorcycle helmets to four standards: DOT, DOT + Snell 2000/2005, DOT + UN/ECE 22 and DOT + BS 6658 [7]. Medium sized full face helmets conforming to a 57cm circumference headform were tested using an ISO "J" headform on a monorail test rig. The results showed some differences between helmet performance across the four impact tests (table 2). Contrary to expectation, the DOT only certified helmets performed best across all four tests and DOT + Snell compliant helmets the worst. However, the test results reveal a pronounced difference between the performance criteria in the standard and the actual performance across a range of impacts. The helmets outperformed the minimum standard.

Table 2.
Summary of comparative helmet testing [7]

	Average Maximum headform acceleration (g)			
Standard Certified	Front Left 2 m Asphalt	Front right 3 m Asphalt	Rear left 2 m Asphalt	Rear right 2 m edge
DOT	157	177	164	138
DOT + ECE	162	192	183	144
DOT + Snell	187	223	198	167

Table 3 presents a similar analysis to table 2, except with AS/NZS 1698 as the common standard. 2-wire guided free fall drop rig with a "M" headform (mass of drop assembly 5.6kg) were undertaken on 19 helmets. The impact test results are very similar, except for depth of penetration where the UN/ECE 22 helmets had the greatest penetration. This is consistent with the absence of a penetration test requirement in UN/ECE 22.

Table 3.
Comparison of Impact Test Performance by Standards Certification. Full Face helmets only (n=19)

	Pooled Standards Certification			
	AS/NZS 1698 only Mean	Snell 2005, not 2010 or UN/ECE Mean	At least Snell 2010 Mean	UN/ECE, Not Snell 2010 Mean
High Energy Impact - average peak acceleration (g)	187.8	179.8	189.5	193.9
Kerb Anvil Impact - average peak acceleration (g)	172.5	171.7	157.2	163.7
Depth of penetration (mm)	23.4	24.8	21.1	30.6

The European COST 327 project reported on a range of motorcycle helmet issues [20]. The crash analyses reinforced the importance of oblique, or tangential loads, in generating head angular acceleration and velocity. Associations between angular head kinematics and injury were observed. Using 60km/h (16.67m/s), the corresponding head impact speed for the 50% cumulative frequency for skull fracture and brain injury, as the benchmark for the impact velocity in an impact energy attenuation test, the drop height would be over 14 m, i.e. much greater than any current test. However, this head impact speed reflects both vertical and horizontal components. All helmet standards test requirements are inconsistent with the observations in the COST 327 report that oblique impacts and resultant angular acceleration contribute to brain injury. On one hand these findings suggest some deficiencies in current standard, on the other, the real world performance of helmets suggests that even in these severe impacts, helmets are offering a great deal of protection to the wearer. The reasons for this include that the helmets may exceed the performance requirements of the standard and the ability of the helmet to attenuate energy in a controlled drop does impart some benefits in oblique impacts.

DISCUSSION

Despite the differences in the performance requirements between the standards, there is no evidence from crash or epidemiological studies that helmets meeting one standard are 'better' than those meeting another. Comparative terms such as "stricter", "tougher", "better" are often used to compare standards, however such terms are inappropriate; the requirements are in most cases just different. Where a standard could be "stricter", for example, is if under the same impact conditions the pass criterion for peak headform acceleration in one standard was lower than another or if there are a larger range of characteristics assessed. The question of 'which is the "strictest" standard', is very difficult to address because of multiple confounding factors. All helmet standards address the characteristics that are considered fundamental to preventing trauma: impact energy attenuation (or acceleration management); stability; retention system strength; vision; and, internal and external projections.

In a 2012 survey of 245 motorcyclists in the Sydney metropolitan region, respondents were asked to rate the level of protection offered by helmets meeting one of five standards and no standard [25]. The analysis showed that AS 1698 compliant helmets were rated significantly higher than other equally rated standards complaint helmets, e.g. Snell and DOT. Helmets not certified to a standard were perceived to offer less protection. This survey is indicative of the importance of brand (standard) recognition and reputation, as well as familiarity. A move to harmonisation of standards would need to address this issue.

Analysis of the results of laboratory testing of motorcycle helmets by the standard to which they are certified, does not reveal any major differences in performance in those tests that would highlight a 'better' helmet in terms of reducing the risk of brain injury. In fact, the laboratory results highlighted the extent that motorcycle helmets, regardless of the standard to which they are certified, exceed the performance requirements and offer a much higher level of protection to the head than might be anticipated. It should be noted that this comment might not apply to all helmets and specifically novelty helmets.

One confounding factor in the available analyses is that most helmets are certified to at least two standards. In some cases, specific requirements in each of two standards, e.g. "dwell time" and high energy impact testing, might lead to a de-facto most stringent standard.

Although on paper the linear acceleration limits set in standards are relatively high in comparison to human tolerance levels (even after consideration for issues of test headform biofidelity), the actual acceleration levels achieved in a range of impact tests are more 'tolerable'. This might indicate the reason that helmets are more effective in real crashes than is suggested by a review of test requirements in standards.

There is still a general need for more information on real crashes and reconstructions of the impact dynamics.

A great deal of research has identified the importance of angular acceleration and/or angular velocity in the mechanism of brain injury, e.g. concussion, bridging vein rupture and diffuse axonal injury. No standard appears to assess the ability of a helmet to reduce optimally angular acceleration in a valid test. Although UN/ECE 22 has a test that appears to assess this characteristic, it is possible that it adds little to the inspection regimes that are in place in other standards. It may be that further improvements in motorcycle helmet performance will arise when this issue is addressed.

A number of oblique test rigs have been developed and reported [26,27,28]. Some included a neck, others not. A device developed at UNSW included a Hybrid III head and neck that was dropped onto a moving striker plate [26]. In lateral impacts from a drop height of 1.5m and landing on the striker plate moving at 35 km/h the mean Head Injury Criterion (HIC_{15}) and mean maximum headform acceleration were respectively 648, 150 g for four helmet models; the mean +αy (neck extension) was +9.5 krad/s^2 and +αx (neck right lateral flexion) was +5.1 krad/s^2. Within many qualifications, the results with and without a neck were comparable. The availability of data from a diverse range of test rigs will assist in discussion about an appropriate oblique impact test method. Further research is required.

It thus appears there are some common deficiencies in all the helmet standards:

- Lack of oblique impact test that can be used to assess the helmet's ability to manage linear and angular head kinematics and minimise brain injury risks;
- Impacts in the real world are frequently below the test line. Therefore, there is an opportunity to assess, and possibly improve, helmet performance across the range of impacts that occur to motorcyclists;
- No standard has a load distribution test (e.g. AS/NZS 2512). This test would be a more suitable method for assessing the effects of

internal projections on head loads specific to the relevant injury mechanisms. It would also be more relevant than the penetration test, in terms of both construction quality and assessing a specific head loading mechanism.
- Head acceleration criteria are too high. The probably cause for the success of helmets is that many manufacturers do not make minimum performance only helmets, but within limits, produce helmets that exceed by a large margin the standard requirements.
- There is confusion concerning the need for repeat impact tests and what they represent. One explanation is that a second impact might occur and the helmet should provide protection in those circumstances. The other explanation is that the first and second impact combined are equivalent to a higher severity impact.
- Consideration for how new technologies may be included inside helmets, e.g. communication devices and emergency management alerts, and how these should be tested to ensure that they do not cause harm.
- Absence, except in UN/ECE 22, of a comprehensive continuous control or batch control processes for motorcycle helmets. Such a system should also require independent approval of the certification bodies and test laboratories, e.g. International Laboratory Accreditation Cooperation, and the prevention of batches of helmets entering the market unless batch testing is successful. There is a real risk that helmets appearing to meet a standard could be dumped in a market when that batch or model no longer complies with the standard.

The potential to harmonise motorcycle helmet standards does exist as do a number of mechanisms, e.g. ISO and UN/ECE. There are also treaties that encourage international harmonisation of standards, e.g. free trade. One barrier is representation. The actual technical aspects of the standard should not necessarily be a barrier to harmonisation, except where the end result would be a standard with fewer requirements and a worsening of performance requirements. The emerging issue may not be harmonisation, rather specialisation might be the key issue.

There exists currently a level of specialisation in helmets, e.g. full-face, open-face, flip-up and motocross. At present these must meet the same performance requirements. JIS T 8133 has a specialisation option based on the intended use. There is a demand for motorcycle helmets that are fit for purpose in different climates and traffic networks. There may also be a need or opportunity for helmets tailored in performance to motorcyclist age.

In Africa and Asia, for example, there is a need and demand for safe helmets but that are suitable for hot and humid climates. Current helmets may not be satisfactory in terms of ventilation and heat dissipation for those climates and may be tuned towards highway speed collisions. A harmonised standard might consider how to address these needs, in the manner of JIS T 8133.

Evident in accident statistics and motorcyclist demographics is the emergence of an older cohort of motorcyclists. It is well understood biomechanically that with age comes a decline in our ability to tolerate impacts. There may also be a need and opportunity to develop versions of standards that are tuned for older motorcyclists.

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