Helmet Stability and Fit in Australian Pedal and Motor Cyclist Populations

K.T. Thai, T.Y. Pang, A.S. McIntosh, E. Schilter
School of Risk and Safety Sciences, The University of New South Wales, Sydney, Australia

ABSTRACT

Background. The ability of a pedal- or motor-cycle helmet to reduce injury to the wearer in the first instance depends on its stability and retention. A helmet may be displaced or even ejected if it has been incorrectly fastened, worn, or inappropriately sized for the wearer's head. Current helmet test standards include a stability test to evaluate the sizing and likelihood of roll-off by applying static or dynamic loads to the helmet when fastened to a standard headform. The relationship between helmet performance tests and helmet stability on rider populations has not been assessed.

Objectives. The main objectives of this study were (1) to assess pedal- and motor-cycle helmet stability and fit in a user population and (2) to assess the appropriateness of the current helmet stability test methods.

Methods. Pedal- and motor-cyclists of various ages, backgrounds and abilities were surveyed over a 3 month period within the Sydney metropolitan area. Anthropometric, demographic and cycling data were collected. Details of the cyclist's helmet were recorded. To assess stability a static pull force was applied to the helmet in situ and as worn by the cyclist. The force required to displace the helmet and the extent of displacement were measured. For some helmets that were loosely worn, the test was repeated after readjustment of the helmet straps.

Results. 269 participants were recruited for the study, yielding 255 usable case data (128 pedal cyclists and 127 motorcyclists). The age range of pedal cyclists surveyed was 4 to 68 years (median 21 years). For motorcyclists, the age range was 20 to 69 years (median of 46 years).

Pedal cyclist head circumference ranged from 50 to 62.5cm (median 56cm) and motorcyclists ranged from 53 to 64.5cm (median 58cm). It was found that 55% of pedal cyclists chose the correct helmet size for their head circumference, compared to 40% of motorcyclists. However, 60% of pedal cyclists wore their helmet incorrectly compared with 10% of motorcyclists. Most helmets (97%) worn met standards that include a stability test. Differences between head dimensions and equivalent headform dimensions of up to 60mm were measured. It was found that an average static load of approximately 6N was required to displace the pedal cycle helmets by 10 degrees in any direction. For full-face motorcycle helmets, this load was 30N and 18N for open-face motorcycle helmets.

Conclusions. In this first survey on this topic, it was observed that up to half of helmet users may be wearing inappropriate helmets for their head size and shape, and that helmet misuse was high, particularly among pedal cyclists. Although most of the helmets worn have passed stability tests, stability in situ was of concern. It was shown that it was easy to displace helmets on user's heads with a static load. This is of particular concern for pedal cycle helmets offering minimal head coverage, where any displacement can expose the cranium to direct impact in a crash.

Keywords. Motorcycle helmet, bicycle helmet, head anthropometry, headform, helmet fit, helmet stability

1. INTRODUCTION

The main purpose of a protective helmet is to reduce the risk of head injury to the wearer by absorbing impact energy during a crash. To achieve this aim, a helmet must in the first instance be worn, and its area of protection must cover the area being impacted. A helmet may be displaced or even ejected if it has been incorrectly fastened, worn, or inappropriately sized for the wearer's head. A well fitting helmet with stable fixation is regarded as being more important for the helmet’s ability to stay on the wearer’s head than the strength of the retention system, and in providing better protection to the wearer in a crash (Andersson et al. 1993; Chang et al. 2001; Parkinson & Hike, 2003; Rivara et al. 1999; Thompson et al. 1997).

In a study on hospitalised child cyclists (head injured and non-head injured helmet users), Rivara et al. (1999) used specialist techniques involving plaster moulding to compare...
measurements of children’s heads with measurements made of the interiors of their helmets when positioned as they would wear them. The researchers found that those who had their helmets tilted posteriorly had a 52% greater risk of head injury than those who had it positioned correctly. It was also found that those with head injuries had helmets that were significantly wider than their heads than those without head injury (Rivara et al. 1999).

In current Australian helmet test standards, fit and stability is assessed using up to five headform sizes for the entire helmet size range. For AS/NZS 2063 Bicycle helmets, a 50N static load is applied to the helmet when fastened to a headform to evaluate the likelihood of roll-off, while in AS/NZS 1698 Protective helmets for vehicle users, a dynamic load is applied to the helmet via a 300mm fall of a 10kg mass. It is not known how these tests relate to helmet stability on Australian rider’s heads.

Thom et al. (2000) reported on a study comparing laboratory dynamic stability tests on motorcycle helmets, using a similar method to the Australian Standard test described above and using both U.S. Department of Transport (DOT) headforms and International Standards Organization (ISO) headforms, with tests performed on 100 human subjects. The subjects were asked to don the helmets and pull forward vigorously. The subjective results reporting the likelihood of ejection were compared with laboratory results to validate the laboratory test method using DOT headforms.

The main objectives of the current study were (1) to assess pedal- and motor-cycle helmet stability and fit in a user population and (2) to assess the appropriateness of the current helmet stability test methods in the Australian Standards.

2. METHOD

2.1 Participants

The sample of 269 participants from the Sydney metropolitan area were recruited and interviewed over a three-month period in 2008. The 255 usable cases consisted of 128 pedal cyclists and 127 motorcyclists. The volunteer participants, including recreational and commuter cyclists and riders were approached at popular recreational sites and stops or recruited through advertisement. Participants were included if they were over 4 years of age, had a helmet for use whilst cycling or riding a motorcycle, and informed consent to participate had been obtained from themselves or a parent (for children under 16 years of age). Participants were given a 15 minute interview in which anthropometric, demographic, riding and helmet use data were collected. Helmet user assessments and fit and stability testing was conducted for each participant. All participants were advised on proper helmet fit and adjustment, and received a $15 gift voucher as compensation for the time spent participating in the study. The study was approved by the University of New South Wales Human Research Ethics Committee.

2.2 Head Anthropometry

Head measurements were taken using a standard flexible measuring tape and anthropometer. The dimensions taken included head circumference measured above the brow, head anterior-posterior length taken as the horizontal distance between the glabella and the occiput, and head width measured as the maximum diameter between the parietal bones above the ears (Figure 1).

Figure 1 Anthropometrical measurements of the head: (a) head length, and (b) head width.

2.3 Helmet Use

Participants’ helmets were examined by the researchers in order to gather data such as size, age, standard compliance, and condition. Participants were also asked to rate their helmet on a five-point scale in terms of comfort, fit, usability, vision and ventilation. Correct helmet use was determined from visual assessment of helmet fit, positioning and adjustment.

2.4 Helmet Stability

To assess the helmet stability, the interior comfort liner of each helmet was fitted with a hook and loop fastener strap before the participant was asked to fasten the helmet ‘as they would normally’. A Mecmesin Advanced Force and Torque Indicator gauge was used to measure the static pull force applied to the helmet in situ by the tester. The force was applied horizontally from the front edge rearward, the rear edge forward, and, for bicycle helmets only, from a side edge towards the opposite side (Figure 2). The minimum force required to displace the helmet and the extent of displacement in degrees of rotation were recorded. If possible, the helmet straps and/or nape adjustment were readjusted by the tester and the test was repeated in order to gauge any improvements.

Figure 2 Static stability test orientations: (a) rearward pull, (b) forward pull, and, (c) sideward pull.

3. RESULTS

3.1 Participants

Pedal cyclists. The 128 pedal cyclists included 60 children under 18 years of age, and 68 adults. The age range of those surveyed was 4 to 68 years (median 21 years). The sample included 95 (74.2%) males and 33 (25.8%) females.
Participants were of European (73.2%), Asian (16.7%), Middle-Eastern (5.8%), Australian-Aboriginal (2.2%), and African (1.4%) ancestry. Ten (7.8%) participants were of mixed ethnic origin.

In terms of hours and/or kilometres spent cycling, 91 (71.1%) participants cycled mainly for recreation, while 36 (28.1%) were commuters. One cyclist mainly cycled competitively. Seventy (54.7%) participants were considered to be infrequent cyclists (less than 2 hours riding per week), 37 (28.9%) were moderate users (2 to 5 hours per week), and 19 (14.8%) were frequent users (more than 5 hours per week). Six (4.7%) of those surveyed were new cyclists with less than a year’s riding experience. Forty-four (34.4%) cyclists were only ever rode as pillion passengers.

Motorcyclists. The age range of the 127 motorcyclists surveyed was 20 to 69 years (median of 46 years). The sample included 98 (77.2%) males and 29 (22.8%) females. Participants were of European (90.6%), Asian (3.1%), Middle-Eastern (3.1%), South and Central American (2.4%), and Australian-Aboriginal (0.8%) ancestry.

One hundred and six (83.5%) participants both commuted by motorcycle and rode for recreation, while 7 (5.5%) claimed to be commuters only, 7 (5.5%) rode only for recreation, and 7 (5.5%) only ever rode as pillion passengers.

3.2 Head Anthropometry and Helmet Sizing

Pedal cyclists. Head circumferences for cyclists ranged from 50 to 62.5cm (median of 56cm). It was found that 70 (54.7%) pedal cyclists chose the appropriate helmet size (or size range) according to their head circumference. Fifteen (11.7%) helmets worn were sized to fit head circumferences smaller than that of the wearer, and 17 (13.3%) were for large head circumferences. For 26 (20.3%) cyclists, the size could not be determined due to worn or missing labels.

Based on the size of the helmet worn, a comparison was made between the dimensions of the wearer’s head and those of the appropriate test headform used in the dynamic stability test, ISO headform A, E, J, M or O (as specified in AS/NZS 2512.7.2:1998 Methods of testing protective helmets. Method 7.2: Determination of stability of protective helmets – Dynamic stability). Large variations were found in head length (32mm shorter to 16mm longer than headform length) and width (24mm narrower to 17mm wider than headform width).

A comparison of head dimensions with all available headform sizes (ISO headforms A to Q as specified in AS/NZS 2512.1:1998 Methods of testing protective helmets – Definitions and headforms) found variations ranging from 29mm shorter to 10mm longer than headform length, and 23mm narrower to 37mm wider than headform width.

3.3 Helmet Use

Pedal cycle helmets. Of the 128 helmets worn by cyclists, 115 (89.8%) bore the appropriate Australian Standard compliance label (AS/NZS 2063). Eighteen (14.1%) helmets were new (manufactured within the last year), and 18 (14.1%) were manufactured more than 5 years prior. The date of manufacture was unclear for 32 (25%) helmets. Most helmets (82.8%) were in good condition; 14.8% were old or worn, and 2.3% damaged.

One-hundred and eleven (86.7%) cyclists stated that they always wore a helmet when cycling, 7.8% wore a helmet most of the time when cycling, 0.8% claimed to wear a helmet half of the time when cycling, and 4.7% stated that they sometimes or rarely wore a helmet when cycling.

When asked to rate their helmet, most cyclists were satisfied with the comfort, fit, usability, vision and ventilation aspects. In terms of fit, 12.5% of participants rated their helmets as ‘Excellent’, 67.2% as ‘Good’, 10.9% as ‘Average’, 8.6% as ‘Poor’ and 0.8% as ‘Very poor’.

It was found that 53.9% of cyclists wore their helmet incorrectly (or not as recommended by the manufacturer). This included 40.6% who wore it loosely, 11.7% wore it too high on their forehead, and 4.7% wore their helmet over other headwear such as caps, visors or bandanas (head scarves).

Motorcycle helmets. One-hundred and twenty (94.5%) of the 127 motorcycle helmets worn bore the appropriate Australian Standard compliance label (AS/NZS 1698). Ninety-seven (76.4%) were full-face helmets, and 30 (23.6%) open-face. Eight (6.3%) motorcycle helmets were manufactured within the last year, and 17 (13.4%) were manufactured more than 5 years prior. The date of manufacture was unclear for 25 (19.7%) helmets. Most helmets (92.9%) were in new or good condition while 7.1% were old or worn.

All motorcyclists surveyed claimed to wear a helmet at all times when riding. When asked to rate their helmet, most motorcyclists were satisfied with the comfort, fit, usability, vision and ventilation aspects. In terms of fit, 29.1% of participants rated their helmets as ‘Excellent’, 52.8% as ‘Good’, and 18.1% as ‘Average’.
3.4 Helmet Stability

Pedal cycle helmets. Pedal cycle helmets were subjected to static pulls in the rearward, forward and sideward directions whilst worn by the cyclists.

For rearward pulls, 51 (39.8%) helmets were not displaced or were minimally displaced (less than 5 degrees rotation). Twenty-seven (21.1%) underwent some rotation (5 to 10 degrees rotation) at an average load of 7.35N. Fifty (39%) helmets underwent significant rearward displacement (more than 10 degrees rotation) at an average load of 5.7N. Sixty-three (49.2%) helmets were tested after readjustment of the helmet. Forty-eight (76.2%) of those adjusted showed a marked decrease in rearward displacement, while 36 (57.1%) had an increase in the pull load (mean difference of 0.52N, sd = 1.94).

For forward pulls, 50% of helmets were not displaced or were minimally displaced (less than 5 degrees rotation). Thirty-one (24.2%) underwent some rotation (5 to 10 degrees rotation) at an average load of 7.95N. Thirty-three (25.8%) underwent significant forward displacement (more than 10 degrees rotation) at an average load of 6.4N. Of the 63 helmets tested after readjustment, 40 (63.5%) showed a marked decrease in forward displacement, while 38 (60.3%) had an increase in the pull load (mean difference of 0.17N, sd = 1.50).

For side pulls, 38.3% of helmets were not displaced or were minimally displaced (less than 5 degrees rotation). Thirty-one (24.2%) underwent some rotation (5 to 10 degrees rotation) at an average load of 6.84N. Forty-six (36%) underwent significant sideward displacement (more than 10 degrees rotation) at an average load of 6.4N. Of the 62 helmets tested after readjustment, 46 (74.2%) showed a marked decrease in sideward displacement, while 38 (60.3%) had an increase in the pull load (mean difference of 0.31N, sd = 1.38).

Motorcycle helmets. Motorcycle helmets were subjected to static pulls in the rearward and forward directions whilst worn by the riders.

For rearward pulls, 90.7% of full-face helmets and 33.4% of open-face helmets, were not displaced or were minimally displaced (less than 5 degrees rotation). Seven (7.2%) full-face helmets and 20 (66.7%) open-face helmets underwent some rotation (5 to 10 degrees rotation) at average loads of 24.4N and 18N respectively. Two (2.1%) full-face helmets underwent significant rearward displacement (more than 10 degrees rotation) at an average load of 27.5N. Seven (5.5%) helmets were tested after readjustment of the helmet. Six (85.7%) of those adjusted showed a marked decrease in rearward displacement, while 5 (71.4%) had an increase in the pull load (mean difference of 2.4N, sd = 0.78).

For forward pulls, 89.7% of full-face helmets and 60% of open-face helmets, were not displaced or were minimally displaced (less than 5 degrees rotation). Eight (8.2%) full-face helmets and 10 (33.3%) open-face helmets underwent some rotation (5 to 10 degrees rotation) at average loads of 23.7N and 17.3N respectively. Two (2.1%) full-face helmets and 2 (6.7%) open-face helmets underwent significant forward displacement (more than 10 degrees rotation) at average loads of 30N and 17.5N respectively. Eight (6.3%) helmets were tested after readjustment of the helmet. Five (62.5%) of those adjusted showed a marked decrease in forward displacement, while 4 (50%) had an increase in the pull load (mean difference of 0.17N, sd = 0.88).

4. DISCUSSION

Fitness and stability are important factors in determining the protective capabilities of a helmet during a crash. In this study of helmet users in Sydney, it was found that while 79.7% of cyclists and 81.9% of motorcyclists rated their helmet fit as either ‘Good’ or ‘Excellent’, only 54.7% of cyclists and 40.2% of motorcyclists wore helmets that were appropriately sized for their head circumference. This suggests that users are uneducated regarding helmet selection for fit, or that helmet sizes are inappropriate for a large proportion of the population.

Of particular concern in this study was the pattern of misuse among pedal cyclists. Incorrect adjustment was evident in both children and adults. With helmet sizes that can have a circumference range of up to 10 centimetres, adjustment is critical for good fit and stability.

Instability of the helmet can be attributed to variations found between head and headform dimensions. This occurs not only when the head dimensions (length or width) are smaller than those of the test headform (and hence the helmet interior), but also when head dimensions exceed those of the headform, which leads to the helmet being worn incorrectly, such as with a larger stand-off between the crown and the helmet interior, or tilted on the forehead. In this study, the differences were found across genders, ages and ethnic groups and were not significantly worse for any particular demographic.

The study was limited to assessing the applicability of the static stability test for both bicycle and motorcycle helmets, as the researchers were unable to obtain ethical approval to perform dynamic pull tests on human subjects. It was found that when in situ, helmets were displaced at pull loads significantly lower than the 50N prescribed in the Standard. Readjustment of the helmet straps and nape mechanisms only gave slight improvements in most cases. This suggests that the current tests may not be appropriate for indicating failures such as poorly designed helmet retention geometries. It is recommended that future test methods take into account helmet misuse to encourage better usability, particularly for pedal cycle helmets.

5. CONCLUSIONS

In this first survey of its kind, it was observed that up to half of helmet users may be wearing inappropriate helmets for their head size and shape, and that helmet misuse was high, particularly among pedal cyclists. It was shown that it was easy to displace helmets on user's heads with a static load. This is of concern particularly for pedal cycle helmets offering minimal head coverage, where any displacement can expose the cranium to direct impact in a crash.

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REFERENCES


