Comparison of Helmet Stability on Headforms and Human Subjects

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Abstract

The ability of a helmet to reduce injury to the wearer in the first instance depends on whether it is securely in place during the impact. A helmet may be displaced or even ejected during a crash if it has been incorrectly fastened, worn, or inappropriately sized for the wearer's head. In the current pedal and motorcycle helmet standards, the propensity of a helmet to roll off the head in a crash is tested on a standard headform by the application of static or dynamic pull loads to the rim. The objective of this study was to assess the relationship between the results of such tests and actual stability on wearers' heads, which may be affected by various factors such as head shape, hair, helmet size chosen, and retention strap adjustment. A group of volunteers recruited for the study were asked to select a comfortable fit from a range of helmet sizes. The minimum static pull load required to displace the helmet on the wearer's head was compared with that on the appropriate size of headform. The relationship between a helmet's performance in the standard test and when tested on human subjects are discussed.

Keywords

Helmet Fit, Headforms, Anthropometry, Test Standards

Introduction

A helmet that is poorly fitted or fastened may be displaced on the wearer's head or even ejected during a pedal or motorcycle crash. It is widely regarded that a helmet with appropriate size and stable fixation is important in providing protection to the wearer in a crash [1,2,3,4,5].

In a study on hospitalised child cyclists (head injured and non-head injured helmet users), Rivara *et al.* [4] 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 [4].

In current Australian helmet test standards, fit and stability is assessed using rigid headforms whose dimensions are based on those in ISO/DIS 6220, *Headforms for use in the testing of protective helmets*. For AS/NZS 2063 *Bicycle helmets*, a 50N static pull load is applied to the helmet, forwards and rearwards, when fastened to an ISO A or J headform to evaluate the likelihood of roll-off, while in AS/NZS 1698 *Protective helmets for vehicle users*, a dynamic pull load is applied in the forward direction to the helmet (on an A, E, J, M or O headform) 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*. [6] 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 wear 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.

In an earlier survey of pedal- and motor-cyclists [7], it was found that up to half of helmet users were wearing helmets that were inappropriate for their head size and shape, and that misuse was high particularly among pedal cyclists. The study involved measurement of the minimum pull loads required to displace helmets on rider's heads. It was found that an average load of 6N was required to displace pedal

cycle helmets by at least 10 degrees, and 18N and 30N for full-face and open-face motorcycle helmets, respectively.

The main objective of the current study was to compare pedal- and motor-cycle helmet stability on headforms and on human subjects.

Methods

Four popular helmet models, based on findings of the previous user study [7], were selected for inclusion in the study. These included two pedal cycle helmets, approved to AS/NZS 2063, and two motorcycle helmets, approved to AS/NZS 1698, in a range of sizes as listed in Table 1 below.

Table 1: Helmet types and sizes tested

Helmet No.	Type	Size	Range (cm)
A1	Pedal cycle	S/M	54-57
A2		M/L	58-62
B3	Pedal cycle	S	53-56
B4		M	56-59
B5		L	59-62
C6	Motorcycle	M	57-58
C7		L	59-60
C8		XL	61-62
D9	Motorcycle	S	55-56
D10		M	57-58
D11		L	59-60
D12		XL	61-62

Seventeen (17) volunteer participants from the RTA Crashlab in Sydney were recruited for the study. The sample consisted of 16 males and 1 female, aged between 24 and 57 years (mean age 36.5). Participants were of European (70.6%), Asian (11.8%), African (5.9%), South Asian (5.9%) and Native Australian (5.9%) ancestry. Subjects were included regardless of their experience with motorcycles or bicycles. Each participant was given a short interview in which anthropometric and demographic data were collected.

Head measurements were taken using standard flexible measuring tapes and an 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 (see Figure 1).
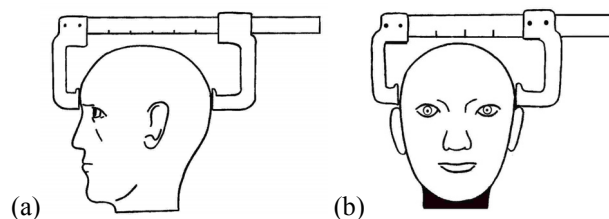

(a)   (b)

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

Each participant was asked to select a helmet size of best fit and comfort from each of the four models provided. During the study, all participants were advised on proper helmet fit and adjustment.

A static pull test was performed on each helmet after optimum adjustments were made to fit the helmet on the subject's head. To perform the test, a hook and loop fastener strap was attached to the interior comfort liner of the helmet. The end of the strap was then hooked onto a digital force gauge, and a tangential pull load was applied to the helmet in the forward and rearward directions. The minimum force required to displace the helmet and the extent of displacement in degrees of rotation were recorded. Where the participant chose a size different to the manufacturer's recommendation (given as head circumference),

the recommended helmet size was also tested if possible. The study was approved by the University of New South Wales Human Research Ethics Committee.

The helmets were then tested on headforms in various configurations with the comfort pads and liners in place for comparison with the human results. The headforms used were those set out in AS/NZS 2512.1 *Methods of testing protective helmets. Definitions and headforms*. The helmets were tested using the methods set out in AS/NZS 2512.7.2 *Determination of stability of protective helmets—Dynamic stability* and using the static pull method as performed on the human subjects.

Results

Measured head circumferences of the subjects ranged from 54.5 to 62 cm (mean 57.9 cm, sd=2.4). It was found that six (35%) participants selected the "correct" sized helmets, i.e. helmet sizes which matched their recommended sizes according to their head circumferences. Four participants (24%) selected mainly correct sizes, 6 (35%) generally chose larger helmets, and 1 (6%) participant chose smaller helmets than what was recommended for his head circumference.

Table 2: Helmet size selection by helmet model

Helmet Size Selection	Helmet Model							
	A		B		C		D	
Size as recommended	12	(71%)	9	(53%)	8	(47%)	7	(41%)
Larger size	4	(24%)	5	(29%)	7	(41%)	6	(35%)
Smaller size	1	(6%)	2	(12%)	1	(6%)	1	(6%)
Couldn't fit any in range	0	(0%)	1	(6%)	0	(0%)	3	(18%)
Recommended size not available	0	(0%)	0	(0%)	1	(6%)	0	(0%)

When comparing subjects' head dimensions with those of the closest matching ISO headforms used in the standard dynamic stability tests (A, E, J, M or O), it was found that subjects' heads were up to 16 mm shorter (mean length difference of 5 mm), and from 13 mm narrower to 14 mm wider (mean width difference of 2 mm) than the headforms.

For pedal cycle helmets, it was found that the average static pull load on human subjects was approximately 23N forwards and 21N rearwards to displace the helmets by 6˚ and 7˚. The same tests were performed on the headforms and using the same helmets and size combinations. The average static pull load on the headforms was approximately 55N forwards and 59N rearwards, with average displacements of 4˚ and 5˚ respectively (Note: For one headform-helmet combination, the helmet came off in the forward pull test. In this case the displacement was graphed as 30˚ but disregarded in the mean calculations) (Figure 2).

For motorcycle helmets, it was found that the average static pull load on human subjects was approximately 35N forwards and 29N rearwards to displace the helmets by 5˚ and 4˚. For headforms, the average pull loads were approximately 63N forwards and 59N rearwards to displace the helmets by 7˚ and 8˚ respectively (Figure 3).

For all helmets, it was found that the differences in loads and displacement between tests on *correctly* and *incorrectly chosen* helmet sizes were insignificant (Figure 4). Similar results were seen in tests performed on matching and mismatched helmet-headform sizes (Figure 5).

All headform-helmet size combinations were also tested to the AS/NZS 1698 requirement for dynamic stability, but in both forward and rearward directions. Except when helmet B5 was tested on headform M (a size-matched pair), all pedal cycle helmets failed the test. Failures were due to the helmet coming off the headform or becoming displaced by more than 30˚. In one case, an anchor point for the rear retention system broke when the helmet was tested on a smaller headform, and in another, the chin-strap buckle broke when the helmet was tested using a larger headform. For motorcycle helmets, all headform-helmet combinations failed the dynamic stability test by rotating more than 30˚ when tested in the rearward direction.
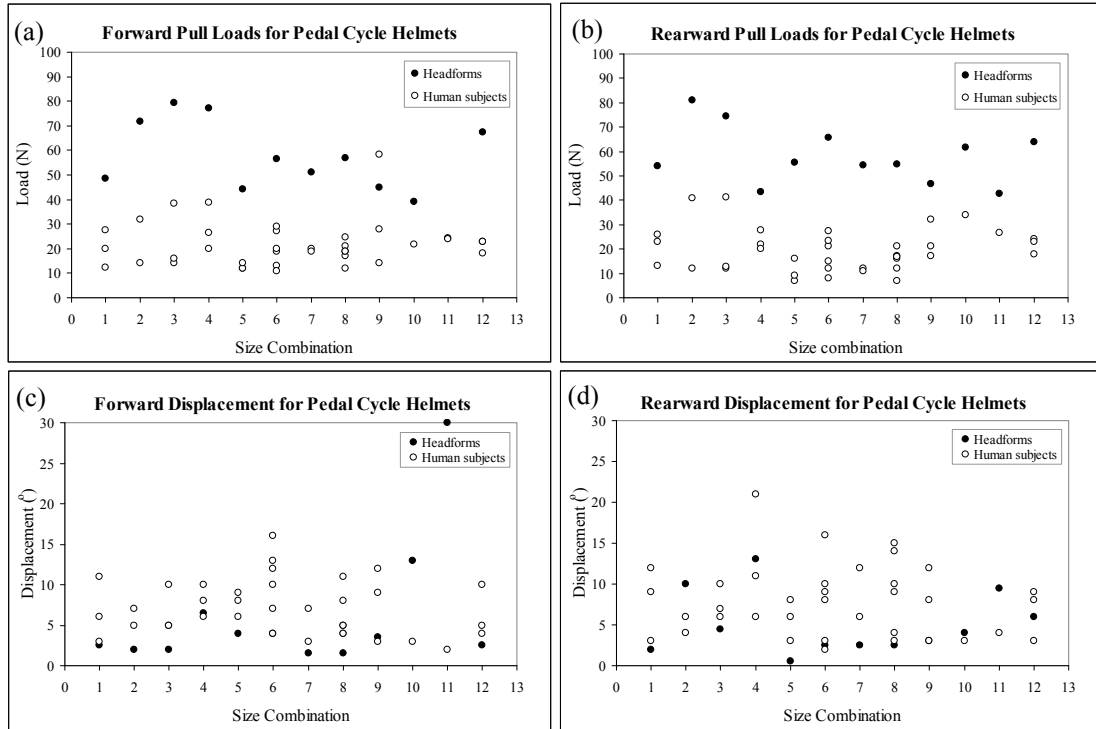
Figure 2: Static pull tests of pedal cycle helmets on human subjects [○] and headforms [•]: (a) Forward pull loads, (b) Rearward pull loads, (c) Forward displacement, and, (d) Rearward displacement.
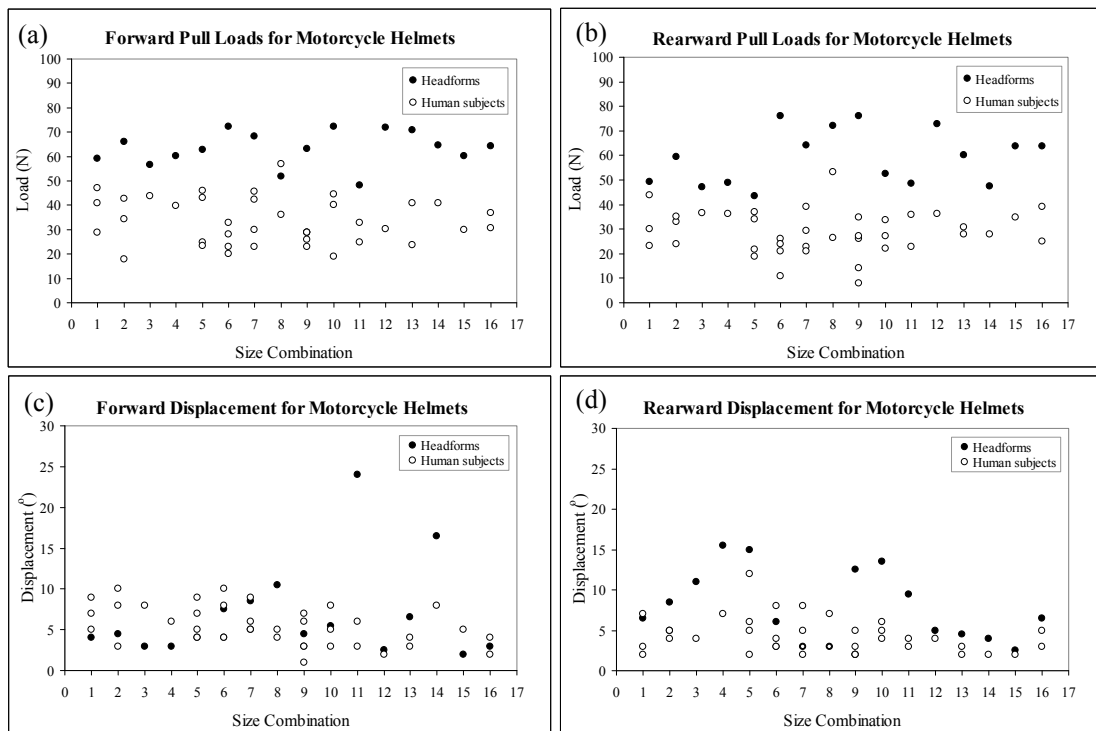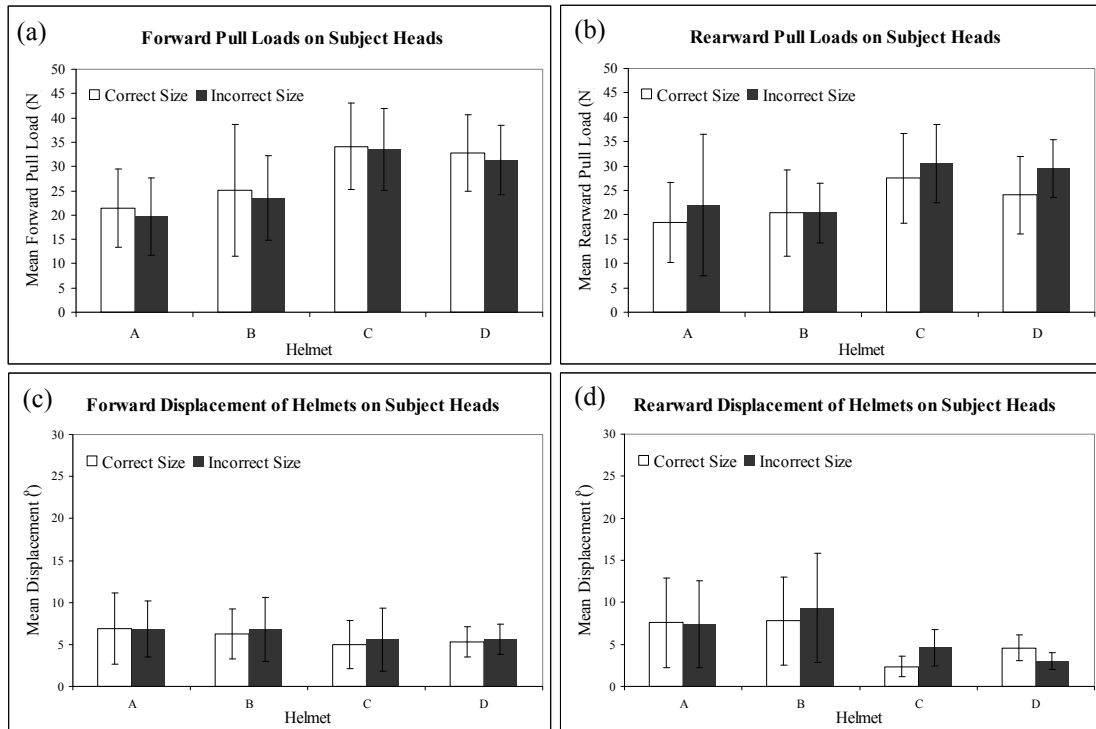

Figure 3: Static pull tests of motorcycle helmets on human subjects [○] and headforms [•]: (a) Forward pull loads, (b) Rearward pull loads, (c) Forward displacement, and, (d) Rearward displacement.

Figure 4: Static pull tests on helmets and subjects of matched vs mismatched sizes: (a) Forward pull loads, (b) Rearward pull loads, (c) Forward displacement, and, (d) Rearward displacement.
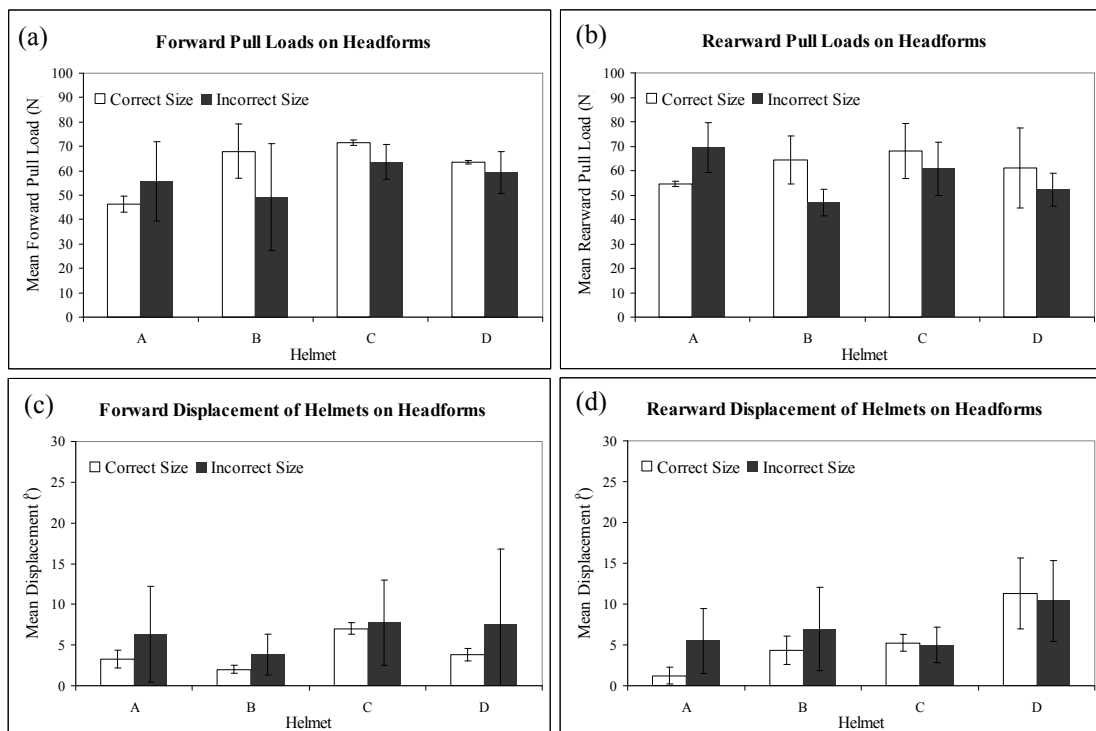Note: Error bars are ± one standard deviation.

Figure 5: Static pull tests on helmets and headforms of matched vs mismatched sizes: (a) Forward pull loads, (b) Rearward pull loads, (c) Forward displacement, and, (d) Rearward displacement.
Note: Error bars are ± one standard deviation.

Discussion

When asked to select helmets according to comfort, it was found that only 35% of wearer's chose the size as recommended by the manufacturer for their head circumference. A comparison of basic head dimensions of subjects and standard headforms revealed only minor differences of up to 14 mm, however these dimensions on which helmet liners are based are central in determining whether a helmet will fit the user. Subjects who chose a larger size than recommended mainly complained that the recommended helmet was too narrow at the sides and caused discomfort at the temples, or ears in the case of the full-face motorcycle helmets.

Size selection was easier with pedal cycle helmets, where the larger size ranges recommended by manufacturers mean the helmets have a larger scope of adjustment. Users can achieve and maintain adequate comfort, especially when a rear adjustment mechanism is included in the design. With this comes an increased margin for error, as fit and stability depends greatly on the adjustment by the user.

For full-face motorcycle helmets, comfort depends most on the helmet shape and the comfort padding rather than the adjustment of the chin strap. Less experienced users were more inclined to choose a larger helmet for comfort, while experienced users chose a snug fit.

In the subject testing, all helmets were adjusted by the tester for optimum fit, which included a comfortable level of slack in the retention system indicated as two finger widths under the chin. A comparison of the results shows that there was very little difference between tests using the *correct* or *incorrect* size on users. This suggests that either the *correct* sizes are not necessarily correct for all users, or that helmet stability depends mainly on adjustment rather than fit at the cranium. In comparison with results from the earlier study [7] on riders' own helmets, the pull loads in this study were as much as 3 times higher for pedal cycle helmets. The reasons for this difference may be that new helmets were used, that the helmets were properly adjusted, and that the helmets were chosen only for fit and comfort in this study rather than style, price, etc. In this test series, none of the helmets actually came off during the static pulls.

When comparing tests on subjects with tests on headforms, using the helmet-headform size combinations chosen by the subjects, it was clear that a better fit could be achieved on the rigid headform by the firmness of the adjustment. The minimum pull loads at which the helmets were displaced were generally 30N higher for tests on headforms than on subjects.

All helmets and size combinations chosen by the test subjects were tested to the dynamic stability requirements of the AS/NZS 1698 standard but with comfort padding in place, and both in the forward and rearward directions. All but one pedal cycle helmet-headform combination failed the requirement. It was clear that the energy of the pull was too high for the pedal cycle helmets, causing some helmets to fail due to failure of the retention strap anchors and buckles.

For motorcycle helmets, all combinations failed when tested in the rearward pull direction. In the forward direction, rotation of the helmet beyond the 30° is somewhat limited by the chin of the headform. Due to the standard only requiring a forward pull, helmet manufacturers can design the retention strap pivot point to optimise performance in this direction only. Certainly many helmets can be adjusted to meet the requirement for one direction. While it is not common for a helmet to roll off due to inertia in the rearward direction, it is possible that an impact to the chin bar or forehead region will cause the helmet to rotate rearward and expose the face, and/or contribute to upper neck or base of skull injuries.

It is recommended that future reviews of the stability test method take into consideration the following:
1. That a certain amount of slack should be introduced in the adjustment of the helmets on headforms to better represent fitment on a user;
2. That the headform size to be used in testing should be clear in the Standard and not left to the discretion of the tester or manufacturer, especially when the size range covers more than one headform size (in which case both headforms should be used); and,
3. That helmet stability should be tested in both forward and rearward directions, possibly without readjustment of the retention system in between the tests.

Conclusions

In this survey of helmet fit and stability in comparison to headform tests, it was found that helmets tended to displace at significantly lower pull loads on users heads than on test headforms. It was also found that helmet sizes are often inappropriate for the user, and that a comfortable fit may perform just as well in terms of stability, provided the helmet is well adjusted to fit, especially for pedal cycle helmets.

Acknowledgments

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