Advanced Cycle Helmet Testing Protocols: Effects of Linear Impact Energy and Compound Impacts

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1 INTRODUCTION

Cyclists are a particularly vulnerable road user with the lack of adequate protection during collisions increasing the risks of serious trauma [1]. In Great Britain, 3,327 cyclists were killed or seriously injured in 2015 alone [2]. During this period, cyclists were observed to be the second most vulnerable road user (VRU) in Great Britain, experiencing a casualty rate of 5,824 casualties/billion cycled miles. Cycle helmets are a vital item of personal protective equipment that aim to reduce head injury severity by providing adequate protection during a collision.

Currently, there is no freely available and independent information provided to consumers at the point of sale to allow them to assess the relative safety performance of cycle helmets. One key reason for this is the need to understand the fundamental science underpinning the development of such protocols. The effects of both impact energy and compound impacts (where a single helmet location is impacted multiple times) on helmet safety performance are currently unknown. This novel research therefore aims to provide the first investigation into the effects of both impact energy and compound impacts, for flat and kerbstone impact anvils, on head injury risks.

2 METHODS

Wire-guided linear drop tests, following Snell B-95C protocols, were performed to assess the effects of impact energy and compound impacts on injury risk. Helmets were securely mounted to a standardised hemispherical headform, before impacting flat and kerbstone shaped anvils at predefined impact locations within the left and right temporal regions of the helmet (Figure 1). Two consecutive drops of each helmet were performed for each impact location. The first drop was performed across a range of heights, whilst the second drop was performed from a height of 1 m only. The first drop height ranged from 1-3 m in 0.5 m increments, whilst helmets were dropped onto either a flat or a kerbstone anvil based upon testing requirements. Various metrics were recorded for each helmet impact and compared against current state-of-the-art head injury criteria. Illustrated in Section 3 are the results for peak head accelerations only.

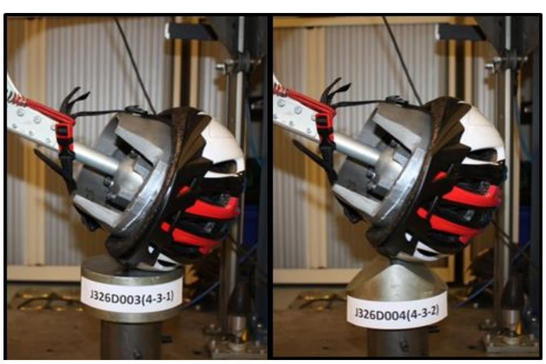

Figure 1: Wire-guided linear headform drop test set-up impacting the right temporal region on the flat and kerbstone anvils

3 RESULTS

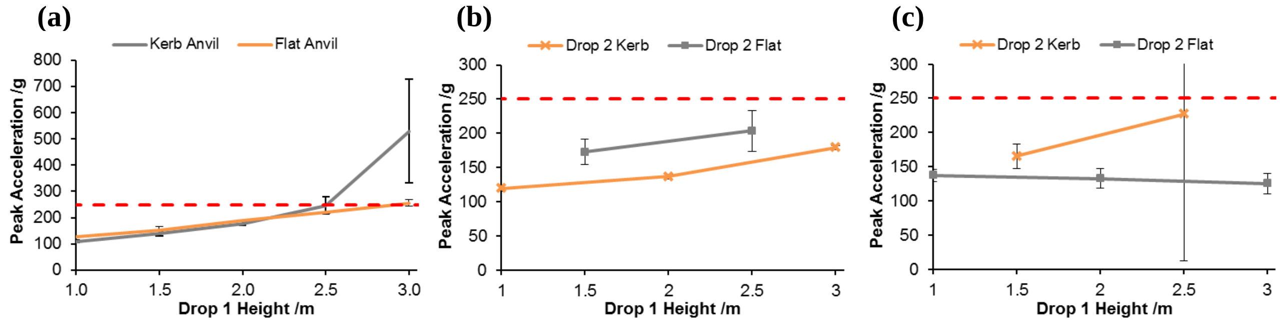

Figure 2: (a) Peak acceleration vs. drop height for the first impact against the flat and kerbstone anvils. Peak acceleration for second impact vs. drop height of first impact against (b) flat and (c) kerbstone anvils. The 250 g threshold line represents the pass/fail criterion for BS EN 1078. Error bars represent the 95% confidence intervals of the mean.

4 DISCUSSION

4.1 Influence of Impact Energy

The results of this research illustrate that increasing the impact energy resulted in greater peak accelerations of the head (Figure 2a). Although increased head accelerations were expected at increased impact energies, it is important to note that the peak head acceleration injury criterion of 250 g (as adopted by BS EN 1078) was only exceeded if helmets were tested at drop heights of >2.0 m. Furthermore, it is clear that the kerbstone anvil caused the helmet structure to bottom out at drop heights of >2.5 m, thus transferring loads directly to the headform. Impact partner shape significantly affected outcomes at greater impact energies, as lower radius of curvature shapes (i.e. kerbstone anvil) caused greater peak accelerations and a greater variation in accelerations at drop heights of >2.5 m. However, at lower impact energies (drop height <2.5m) the kerbstone anvil resulted in lower head accelerations than the flat anvil. This is due to the fact that the kerbstone anvil spreads loads over a much smaller surface area than the flat anvil, resulting in greater penetration of the helmet and causing damage to the EPS structure of the helmet at greater depths. At drop heights <2.5 m, however, the smaller surface area of the kerbstone anvil resulted in lower opposing forces from the helmet structure, which in turn lowered the peak head accelerations.

4.2 Influence of Compound Impacts

When observing the effects of the impact energy of the first impact on the outcomes of the second impact, two variables clearly affected the safety performance of the helmets during compound impacts (Figures 2b and 2c). Firstly, the greater the overlap in impact partner shape, the greater the peak head accelerations experienced during the compound impact. Secondly, if impact partner shapes significantly overlapped, the greater the energy of the first impact, the greater the peak accelerations experienced during the compound impact. When considering compound impacts, the amount that the impact partner shapes overlap (Figure 3) was found to markedly influence outcome.

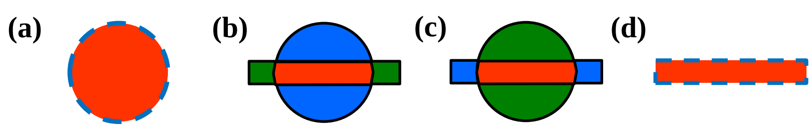

Figure 3: Schematic of impact partner shape overlap areas for the following impact sequences (a) flat-flat, (b) flat-kerbstone, (c) kerbstone-flat and (d) kerbstone-kerbstone. The initial impacts are illustrated in blue, overlapping compound impact areas are red and non-overlapping compound impact areas are green.

The use of the flat anvil for the initial impact resulted in large areas of damage to the EPS structure of the helmet. Thus, the second impact with the flat anvil almost entirely strikes an already damaged part of the helmet, resulting in the loads being transferred directly to the headform. A similar effect was produced when the compound impacts involved two drops onto a kerbstone anvil. High and widely varying head accelerations were produced due to the focussed impacts directed onto an area of already highly damaged EPS material. Compound impacts involving anvils of differing profile led to lower head accelerations than those involving anvils of the same profile. This was due to the anvil in the second drop impacting a portion of the undamaged EPS material therefore reducing the accelerations experienced by the headform. It was noted that, for a drop height of only 1 m, compound impacts considerably increased the risks of injury. When impact partner shapes were observed to significantly overlap and the drop height of the first impact was >2.0 m, the head accelerations experienced during a 1 m drop approached those experienced by the headform in the initial impact

5 IMPLICATIONS FOR FUTURE PROTOCOLS

This research shows that helmet safety performance can vary with impact energy, impact partner shape and when the helmet is impacted multiple times at the same location (compound impacts). Although this research provides key guidance on what effects these variables have on outcome, it also identifies which tests may be unsuitable for future protocols. Large variations in outcome were observed when the helmet was impacted against the kerbstone anvil from a drop height of >2.0 m and when the compound impact involved a drop onto a kerbstone anvil followed another drop onto a kerbstone anvil. As repeatable outcomes are critical to a well-designed test and assessment protocol, these large variations prohibit the inclusions of these tests in the protocols. The compound impact tests described in this research could be a key test for differentiating between the protective qualities of helmet models. Further comparisons against cyclist collision data are required to evaluate the relative importance of these testing and assessment protocols. Weightings should be developed to ensure that the outcomes of each test are weighted against the relative real-world importance of each injury mechanism. Additional research, looking at whether these tests can be used as a key differentiator for assessing the safety performance of helmet models, will be performed in the future test packages.

6 CONCLUSIONS

Impact energies, impact partner shapes and compound impacts have all been shown to affect the safety performance of helmets. Higher impact energies were found to result in greater peak head accelerations. Although significant damage to the helmet was caused by the kerbstone anvil for drop heights of >2.0 m, high energy impacts onto the flat anvil were experienced by the helmet from a drop height of 3.0 m without significant damage being caused. Compound impacts were principally affected by the proportion of damaged material engaged by the second impact. The kerbstone anvil caused a significant increase in peak head accelerations at impact drop heights of >2.0 m and after being initially impacted by a kerbstone anvil. Advanced testing protocols may need to recognise and assess the relative safety performance of cycle helmets against these variables.

ACKNOWLEDGEMENTS

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