Differences in bicycle helmet performance under real-world impact conditions using standard and oblique test rigs

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Introduction: Cycling is the leading cause of sport-related head injuries in the US. Bicycle helmets must comply with safety standards limiting peak linear acceleration (PLA) to <300 g in impact testing. However, limited data are available on which helmet designs offer superior protection, and standards tests are more severe than common cyclist accidents (~100 g). Standards also do not test the helmet rim, a common real-world impact location. Additionally, standards conduct normal impacts and measure only PLA, while real-world accidents are oblique and involve rotational acceleration, a major contributor to brain injury.

Objective: To investigate differences in the protective capabilities of bicycle helmets under real-world conditions using normal versus oblique impacts.
Methodology: Ten varied helmet models were tested on a CPSC standard drop rig with a flat anvil (normal) and on a custom oblique drop tower with a 30° anvil. Two impact locations (frontal rim, temporal) and one impact velocity were selected to reflect real-world conditions. A higher velocity was also chosen per rig: a standard-specified velocity for normal impacts and a more moderate velocity for oblique. The two locations and velocities produced four impact configurations per rig. Each configuration was tested four times per model, totaling 320 impact tests. PLA was determined for all tests, as well as peak rotational acceleration (PRA) for oblique impacts. Concussion risk was then calculated for oblique impacts using a risk function combining PLA and PRA. Results were compared across helmets using ANOVA, while helmet rank order (based on PLA for normal impacts and concussion risk for oblique) was compared across configuration and rig using nonparametric correlation statistics.

Results: Large ranges in accelerations were observed for both rigs, with many significant differences between models. PLA averaged 105±22 g for normal impacts and 109±24 g for oblique impacts at the low velocity, and 227±46 g for normal and 154±27 g for oblique at the high velocity. Temporal PLAs were higher for both rigs, with the exception of several frontal PLAs that would have failed the CPSC standard. PRA for oblique impacts averaged 4.6±0.7 krad/s2 and 6.2±1.1 krad/s2 at the low and high velocities. These impacts produced concussion risks ranging from 2-99%, spanning over 60% in single configurations. Helmet rank order was significantly correlated across configuration and impact type, although variations in PRA across models altered rank order for oblique impacts.

Conclusions: These results reveal large differences in bicycle helmet performance under real-world conditions. The temporal location generally produced higher PLAs, likely due to higher effective liner stiffness, while several frontal impacts produced extremely high PLAs, suggesting that standards testing should be expanded to include the helmet rim. Overall, helmet performance was similar across configurations and impact type, but several helmets had significantly greater PRAs in oblique impacts, producing higher concussion risks and influencing relative rank order. In light of this, there appears to be clinical value in assessing helmet performance under oblique impacts rather than solely standard normal impacts. These results can be used to inform standards testing, leading to improved bicycle helmet safety.