

METHODOLOGY FOR RECONSTRUCTING REAL-WORLD DAMAGE TO BICYCLE HELMETS USING OBLIQUE IMPACTS: A CASE STUDY

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ABSTRACT

Cyclist head impact conditions and resulting kinematics are not well understood. One avenue for investigating these impacts is to reconstruct residual damage from helmets involved in real-world accidents using laboratory testing. To date, reconstruction studies have assessed normal-velocity impacts and linear accelerations. In reality, cyclist head impacts are oblique and involve both linear and rotational kinematics, an important combination in producing brain injury. The present study details a method for reconstructing bicycle helmet damage using oblique impacts and advanced damage quantification techniques. Damage to a helmet involved in a cyclist accident was quantified using computed tomography (CT). Scrape length and crush depth, area, volume, and centeredness were evaluated. Impact testing to identical, undamaged samples was then conducted, with impact angle and velocity successively updated based on visual observation of damage. Damage was then quantified using CT and compared to the original damage, and linear regression models were generated to relate each damage metric to applied normal and tangential velocities. Linear and rotational head impact kinematics were also recorded. These methods show promise for reconstructing real-world bicycle helmet damage, which can enhance understanding of cyclist head impact conditions and enable improved helmet design.

Keywords: cycling, head injury, impact conditions, kinematics, biomechanics

INTRODUCTION

Cycling is the leading cause of sport- and recreation-related head injuries in the US. [1]. Although helmet use reduces injury risk [2], safety standards evaluate bicycle helmet performance using tests that do not reflect typical cyclist head impacts. Standards instruct that a helmeted headform be dropped onto an anvil at an angle normal to its surface while headform linear acceleration is recorded [3]. Real-world cyclist head impacts involve normal and tangential velocities (termed "oblique") and induce rotational impact kinematics as well as linear [4, 5], an important interplay leading to brain injury [6, 7]. Despite knowledge of the oblique nature of these impacts, exact cyclist head impact conditions and kinematics are relatively unknown. Better understanding of these impacts could aid in optimizing helmet design.

Cyclist head impact kinematics have traditionally been investigated via two means: computational simulation of cyclist crashes [4, 5], or post-crash laboratory reconstructions of residual helmet damage [8-10]. Simulations are useful for gleaning trends pertaining to cyclist head impacts, but their accuracy relies on the computational model validity. As cyclists do not often wear instrumentation capable of measuring head impact kinematics, data from real-world cyclist head impacts are largely unavailable, limiting the validation of computational models for these scenarios.

Damage reconstructions provide an additional avenue for ascertaining cyclist head impact conditions. Bicycle helmet expanded polystyrene (EPS) liners dissipate energy by permanently crushing on impact. The damage can be matched on identical helmets through laboratory impact tests to deduce the nature of the impact. However, previous damage reconstruction studies are restricted by use of standards equipment