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A Novel Video-Based Method to Estimate Helmet Pad Deformation During Impact

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ABSTRACT

Understanding the mechanical behavior of helmet components during impact has quickly become a critical issue to better protect American football players from mild traumatic brain injuries. These injuries can have long-lasting effects on the brain structure and function, potentially contributing to neurodegenerative conditions. In response, the National Football League has implemented stricter guidelines and rules to protect players from dangerous tackles. Additionally, they have developed multiple helmet testing protocols to comprehensively evaluate helmet safety by measuring the translational and rotational kinematics of a standardized headform during impacts at various speeds and locations. A helmet performance score (HPS) is then derived from the collected data, providing a valuable metric for comparing helmet safety. However, limited information is available regarding the energy absorption mechanisms and mechanical behavior of helmet components during impact.

This study presents a novel three-dimensional video-based method for estimating helmet pad deformation during impact. Following the NFL helmet protocol, impacts were performed at three speeds (5.5 m/s, 7.4 m/s, 9.3 m/s) at the side upper (SU) location on three helmet configurations using a pneumatic linear ram impactor. Each helmet configuration had distinct 3D-printed lattice padding structures at the SU position. The shell, facemask, chinstrap, and other pads were identical across all configurations, ensuring consistency in the other variables. Head acceleration and video data were recorded using nine accelerometers and two high-speed cameras. After testing, a partial HPS for the SU location was calculated from the acceleration curves for each helmet. Additionally, the relative position coordinates of the headform and impactor were determined for each frame by tracking five markers placed on each component. The 3D video analysis then generated two coordinate systems, with the impactor's position set as the origin. These coordinates were imported into CAD modeling software to virtually reconstruct the impact, enabling the calculation of the minimum distance between the impactor and the headform over time. This minimum distance was used to estimate the maximum deformation of the SU padding structures. Differences in maximum deformation were observed among the three helmet configurations (ranging from 46.6 to 95.8%) across all impact speeds. By correlating this metric with the stress-strain behavior of the lattice structures in each configuration, it was possible to identify those that reached densification during testing. This densification corresponded with a higher partial HPS, indicating reduced helmet safety. This method enhances the understanding of helmet performance and provides a valuable metric for improving helmet design.