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Topic: Occupant Injury Biomechanics; Risk of Head Impact

Title: High-energy Head Impacts in Athletes to the Side and Rear Cause Observable Deficits, Similar Magnitude Impacts to the Front Do Not Cause Observable Deficits

Abstract

Background

The relationship between single head impact dose and immediately observable functional deficits post-impact has been debated for nearly eight decades. Early work by Holbourn (1941) and later work by Newman et al. (1999, 2000) and Elkin et al. (2018) suggested high energy head impacts would be more tolerable to the forehead than either the side or rear of the head. Recent work by Guskiewicz & Mihalik (2011) proposed that acceleration-based dosimetry was ‘clinically irrelevant’ due to the lack of an observed relationship between observed functional deficits and scalar acceleration-based input dosing for single impacts.

Study Aims

In this study we aimed to quantify single head impact doses with high accuracy and precision, and then use video verification to categorize high-energy impacts as “No-go” events per the National Football League’s standard protocol (NFL, 2018). An impact monitoring mouthguard (IMM) system was used to collect the laboratory and on-field data.

Methods

To confirm IMM accuracy and precision we conducted n=1011 laboratory calibration tests using both Hybrid III and NOCSAE anthropomorphic test devices impacted at multiple locations and kinetic energy transfer of approximately 5J to 150J (nominal peak scalar linear accelerations ranging from 20g to 120g).

On-field, we retrospectively analyzed 4390 video-verified head impacts in American football, ice hockey and combat sport athletes over 752 player-games using the IMM system to estimate high-risk impact doses. Any event where the player was observed to have immediate post-impact behavioral deficits meeting the NFL “No-go” criteria was identified.

Results

In laboratory tests versus Reference, the IMM fit a linear model well for all kinematic parameters of peak scalar linear acceleration (PLA), peak angular acceleration (PAA), peak linear velocity (PLV) and peak angular velocity (PAV). The slope ranged from 0.95 to 0.99 and R^2 ranged from 0.92 to 0.98.

During gameplay, the median PLA, PAA, PLV, PAV, kinetic energy transfer (KE) and Risk-Weighted Exposure (RWE) were 21g, 1600rad/s^2, 12rad/s, 1.5m/s, 6J and 0.00002, respectively. Approximately 90% of impacts were to the front and sides of the head.

Of the nine (9) highest energy impacts to the side and rear of the head, all were “No-go” impacts. The magnitude of KE transfer was of 40J to 110J and was 1-2 orders of magnitude higher than the median. Of the top eight (8) highest energy impacts to the front of the head none were “No-go” impacts. These impacts had KE transfer of 50J to 70J.

Conclusions

The difference in “No-go” observations for high energy impacts to the side and rear of the head versus frontal impacts confirmed predictions made by several authors dating back to Holbourn in 1941. Our data define a clear, albeit preliminary, relationship between impact dose, impact direction and functional deficit threshold that has not been previously found from live human data. Future work will be focused on expanding the depth and breadth of head impact doses to confirm these findings. Regardless, the dose-response relationship found in this study could be useful to estimate injury risk for laboratory and on-field impacts of similar impact magnitude, frequency content and impact location.