

Deriving Representative Head Impact Profiles in Contact Sports: A Shape-Based Clustering Approach

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Introduction:

Contact sports such as rugby, boxing, mixed martial arts (MMA) and ice hockey expose athletes to repetitive head impacts, which can cause traumatic brain injury (TBI). To quantify the head kinematics produced by these impacts, wearable technologies have been deployed. Due to their coupling to the maxillary dentition, instrumented mouthguards (iMGs) are promising a more accurate means of characterising head kinematics, leading to their increasing use for monitoring traumatic brain injuries in sporting events. However, a standardised methodology for assessing their accuracy in experimental or computational settings remains undefined. Such methodology should recreate representative impact conditions based on field data.

Objective:

The objective of this study is to determine representative impact conditions and head kinematic profiles based on the most probable impact scenarios observed in real-world play.

Methodology:

Raw iMG data were gathered from three sports—boxing, MMA, and rugby union—using the PROTECHT mouthguard by Sport and Wellbeing Analytics (SWA). The iMG utilises a tri-axial accelerometer (sampling at 1 kHz, ± 400 g) and a tri-axial gyroscope (sampling at 1 kHz, ± 35 rad.s⁻¹).

For each impact event, the iMG captured a 104 ms window: 10 ms of pre-trigger data and 94 ms post-trigger. The recording trigger was defined as a raw linear acceleration exceeding 10g in any single axis. Sensor axes were aligned with anatomical planes. Data were then filtered using a Hampel and a 4th-order low-pass Butterworth filter with a cut-off frequency of 160 Hz. Rotational acceleration was derived via a five-point stencil derivative. Finally, filtered linear acceleration data were translated from the mouthguard origin to the head's centre of mass.

Our database consisted of 3,717 labelled head impacts across Boxing (1,655), Rugby Union (1,616), MMA (446), with internal labels allowing for subgrouping by impact type (cross, jab, uppercut, etc). A quality filter ($impacts < 5$ or $\frac{\text{optimal number of clusters}}{impacts} > 0.5$) excluded 11 unstable groups, leaving 22 stable impact groups. Smaller working sets facilitated a hierarchical clustering approach. In contrast to previous studies that extract features from the head kinematic waveforms, e.g. peak linear acceleration and peak rotational acceleration, we maintained the entire waveforms to determine representative waveforms required for experimental or computational simulations. The Dynamic Time Warping (DTW) approach was used to determine clusters in the waveforms, as the shape-based distance metric. Clusters were evaluated using the silhouette coefficient, the elbow method, and the Dunn index to determine the

optimal number of clusters. Once clustering was conducted, representative impacts were compared against the initial dataset to examine similarity based on the kinematic peak values and the resulting brain strain.

Results:

We identified 63 representative waveforms (medoids) across the three sports by selecting the real impact minimising total intracluster DTW distance. Statistical analysis confirmed that the medoid central tendency was statistically indistinguishable from the full dataset for all metrics across every sport.

Conclusions

Time-series clustering successfully identified distinct impact profiles that can serve as representative waveforms providing sport-specific, biofidelic loading conditions essential for accurate simulations and instrumented mouthguard validation, moving beyond scalar peak value testing.