Head Impact Exposure and Strain-Based Injury Prediction Across Youth Ice Hockey

Taylor Sims, Clara Karton, Parisa Dehghan, Amir Azadi, Thomas B. Hoshizaki

I. INTRODUCTION

Youth ice hockey accounts for the vast majority of Canadian hockey participation, yet the majority of head-impact research and helmet evaluation methods are based on elite adult data and kinematic metrics [1]. While exposure studies quantify impact frequency and mechanisms, they do not directly reflect brain tissue response. Maximum Principal Strain (MPS) has emerged as an important brain injury metric, but its use is limited by computational demands [2]. This study integrates real-life video-based exposure data with finite element (FE) modelling to characterise age- and sex-specific head impact profiles and evaluate linear and nonlinear models relating reconstructed head dynamic response to MPS for injury prediction.

II. METHODS

Video analysis was conducted on 319 youth ice hockey games (male and female) across the Learn to Play (5–8 year-old (yo)), elite non-contact (14–17yo), and elite contact (14–17yo) divisions. A head impact event was defined as any contact involving the head and the ice, boards/glass, another player, puck, or stick. For each event, player characteristics, impact type, location on head, and estimated closing velocity (calculated using Kinovea) were recorded. A subset of impacts underwent laboratory-based reconstructions. PLA (Peak Linear Acceleration) and PRA (Peak Rotational Acceleration) were obtained from these reconstructions of representative impacts selected from the video-derived exposure data. The reconstructed impacts were then processed using the University College Dublin Brain Trauma Model (UCDBTM v.2) FE brain model to calculate the MPS. Impact types were grouped according to the exposure populations identified through video analysis: Learn to Play, competitive contact male, and competitive contact female (Fig. 1).

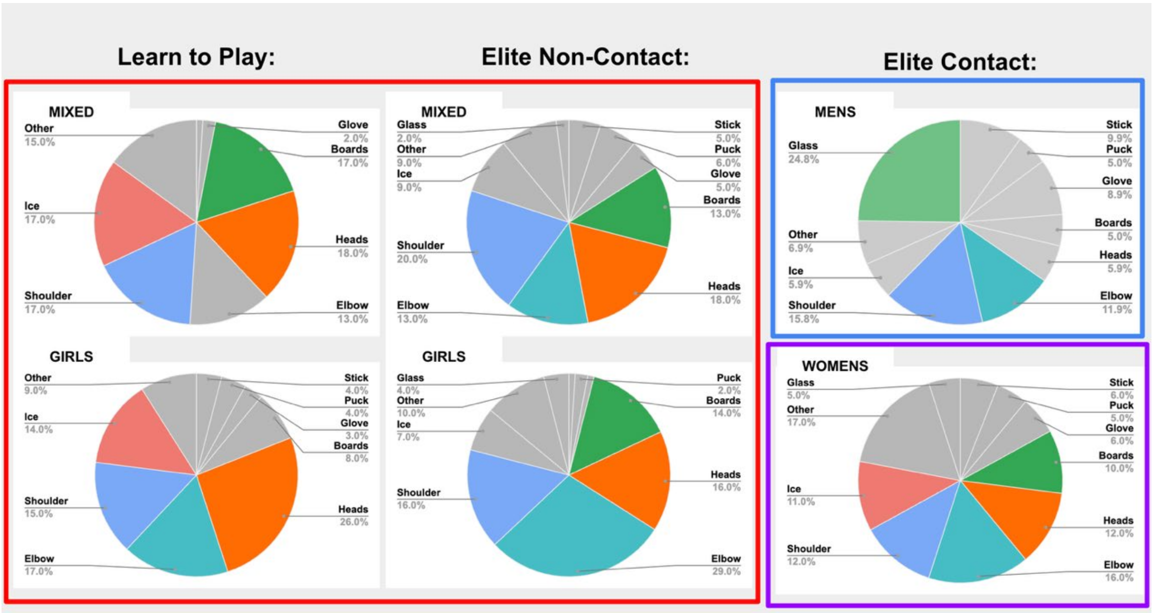

Fig. 1. Head impact exposure distributed by impact type across age, level, and sex.

Based on the impact data from video analysis, a total of 304 reconstructed impacts were grouped into Learn to Play, competitive contact male and competitive contact female datasets. Single-variable linear (Peak Linear Acceleration (PLA), Peak Rotational Acceleration (PRA)), multiple linear, and nonlinear (Random Forest) models were implemented and evaluated to predict MPS and to assess the need for group-specific injury prediction

T. Sims (e-mail: tsims041@uottawa.ca) is a PhD student in Biomechanics, C. Karton is a researcher in Biomechanics, P. Dehghan is a Post Doctoral student in Biomechanics, A. Azadi is a Post Doctoral student in Biomechanics and T. B. Hoshizaki is a Professor of Biomechanics, all at University of Ottawa in Canada.

algorithms.

III. INITIAL FINDINGS

A total of 1,370 head impacts were identified, highlighting distinct exposure profiles across groups. Learn to Play athletes experienced primarily low-magnitude (<20 g), fall-related impacts. Elite female players exhibited moderate-magnitude (10–35 g) impacts dominated by elbow and shoulder contact, while elite male players experienced higher-magnitude impacts (up to 70+ g), frequently involving glass and player-on-player contact.

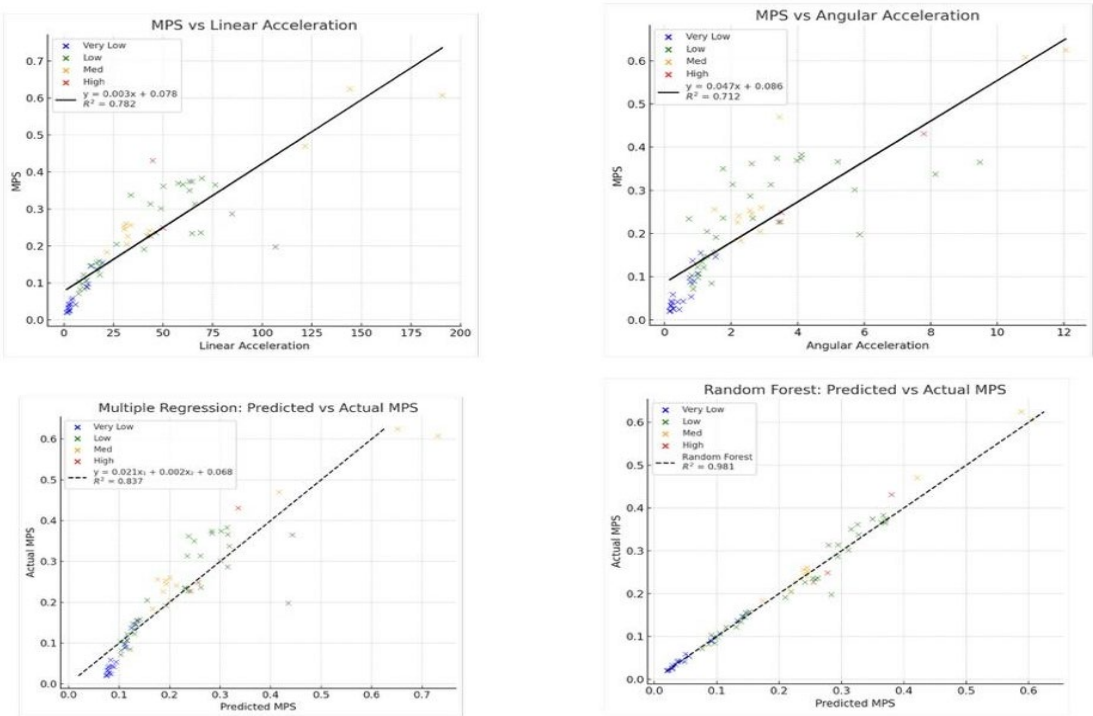

Fig. 2. Model performance for competitive contact women's group: single-variable linear regression using PLA and PRA as prediction for MPS and multivariable models using multiple linear regression and Random Forest. Each panel shows the fitted relationship between the kinematic predictor(s) and FE-derived MPS.

Across the reconstructed datasets, nonlinear models outperformed linear approaches. Random Forest produced the highest accuracy across locations, with R^2 values of 0.91 (front), 0.99 (front boss), and 0.92 (side), compared with much lower performance from single-variable and multiple linear regressions. Polynomial models consistently overfit. Random Forest again yielded the strongest performance for Learn to Play, competitive contact men, and competitive contact women, including superior generalisation on held-out test sets. These results show that group-specific algorithms are best represented by nonlinear modelling, supporting injury prediction relationships that differ across age, competition level, and sex.

IV. DISCUSSION

Head impact exposure in youth ice hockey varies by age and sex, competition level, and rules of play resulting in distinct impact characteristics and biomechanical responses. Learn to Play athletes sustain frequent but low-severity impacts, whereas older competitive groups experience higher-magnitude impacts and greater variability in impact event types. These differences in exposure characteristics likely influence the relationship between kinematics and brain strain, explaining the improved predictive performance of nonlinear models. Integrating exposure data with strain-based prediction provides a more complete understanding of injury risk and supports the development of group-specific helmet evaluation metrics and safety standards.

V. REFERENCES

[1] Levy, Y., *et al.*, *Ann Biomed Eng*, 2021.
[2] Zhang, Y., *et al.*, *J Bioeng*, 2024.