Gender differences and influence of impact mechanism and location on head impact kinematics in high school soccer

Huber, Colin M[1].; Patton, Declan A.[1]; McDonald, Catherine C.[2]; Durbin, William R.[1]; Simms, Katherine[3]; Wofford, Kathryn L.[4]; Jenkins, Kayleigh[5]; Cullen, D. Kacy[6]; Master, Christina L.[7]; Arbogast, Kristy B.[8]

[1]Center for Injury Research and Prevention (CIRP), Children's Hospital of Philadelphia; University of Pennsylvania, Department of Bioengineering
[2]University of Pennsylvania, School of Nursing
[3]University of Pennsylvania, Department of Bioengineering
[4]Drexel University, School of Biomedical Engineering, Science and Health Systems; Corporal Michael J. Crescenz VA Medical Center, Center for Neurotrauma, Neurodegeneration & Restoration; University of Pennsylvania, Department of Neurosurgery
[5]The Shipley School
[6]University of Pennsylvania, Departments of Neurosurgery & Bioengineering
[7]Center for Injury Research and Prevention (CIRP), Sports Medicine and Performance Center, Children's Hospital of Philadelphia; University of Pennsylvania, Perelman School of Medicine
[8]Center for Injury Research and Prevention (CIRP), Children's Hospital of Philadelphia; University of Pennsylvania, Perelman School of Medicine Department of Pediatrics

Background: An estimated 1.6-3.8 million sports- and recreation-related mild traumatic brain injuries occur in the U.S. annually. Adolescents are particularly vulnerable due to slower recovery times, higher injury rates, and under-reporting. In equivalent sports, females have a higher incidence of concussion possibly attributed to differences in head impact kinematics due to cervical strength, head mass, and impact rate. Further, there is growing concern for long-term effects of repeated head impacts that may not cause immediate symptoms. Head impact sensors can be used to measure head kinematics in contact sports, but for understanding and identifying on-field head impacts, data must be interpreted in the context of laboratory validation of the sensor system and utilize video confirmation methods.

Objective: To characterize gender differences and the effect of impact location and mechanism on head impact kinematics in high school and compare data acquired in the real-world with similar data collected in a controlled laboratory setting

Methods: Male and female high school soccer teams wore headband-mounted head impact sensors (SIM-G, Triax Technologies, Inc) during games for two seasons (2017-2018). Sensor impacts were confirmed and categorized through time-synchronized video analysis by impact mechanism (head-to-ball, fall, player contact) and location (front, side, crown, rear). To help interpret on-field data, laboratory validation studies were conducted to assess intrinsic sensor accuracy. Specifically, two SIM-G sensors were rigidly attached to an adapted HYGE™ pneumatic device that induces a characterized and calibrated pure rotation. Five peak rotational velocities were explored, with two sensors per trial, for a total of 55 trials. SIM-G measures were compared to reference measures of rotational velocity from the HYGE.

Results: Data were collected for 889 player-games (509 male). After detailed video analysis, 1305 (1034 male) impacts were identified; 79% were head-to-ball, 10% were falls, 11% were player contact. These percentages were similar between males and females. Head-to-ball impacts resulted in significantly higher peak angular velocities (23.3±10.3 rad/s) than player contacts (18.1±8.9 rad/s; $p<0.001$) or falls (15.1±7.5 rad/s; $p<0.001$). Further, females had significantly higher rotational velocities from player contacts (21.7±8.6 rad/s) than males (17.3±8.8 rad/s, $p=0.03$). Of the head-to-ball impacts, the distribution of impact location was: 50% front, 7% rear, 20% side, 24% crown. Impact severity varied by impact location: for males, rear impacts (23.8±8.2 rad/s) were greater than front (17.6±6.6 rad/s), for females, this relationship was reversed (rear: 16.6±7.1 rad/s vs front: 20.8±7.7 rad/s). Based on laboratory tests, SIM-G sensors had high inter-sensor reliability ($R^2>0.99$) and correlated strongly with the reference ($R^2>0.99$) but consistently underestimated peak rotational velocity (3.5±1.2 rad/s underestimation (15%); $p=0.005$), suggesting that the on-field measures reported above are less than what participants actually experienced.

Conclusion: Head impact mechanism influenced rotational kinematics with head-to-ball impacts having the highest magnitude. Among head-to-ball impacts, gender differences in impact severity by impact location were observed. Laboratory data demonstrated that the sensors provide repeatable measures that correlate to reference values with a slight underestimation of 15%. These on-field data further our understanding of gender differences in impact characteristics that may ultimately help explain injury rate disparities.