On-field Instrumented Mouthguard Coupling

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Introduction: Structural and functional brain changes have been observed with the accumulation of head impacts that do not cause typical concussion symptoms nor result in a diagnosed concussion, also known as subconcussive impacts [1,2]. To understand the short- and long-term risk of sports-related brain trauma, we must first quantify the exposure to repetitive head acceleration events (HAE). Instrumented mouthguard (iMG) sensors have been developed to measure sports HAEs in brain injury research [3]. Laboratory validation studies show that effective coupling of iMGs with the human skull is crucial for accurate head kinematics measurements [4]. However, iMG-skull coupling has not been investigated in on-field sports settings. The objective of this study was to assess on-field iMG coupling using infrared proximity (IR) sensing and to investigate coupling effects on kinematics signal characteristics.

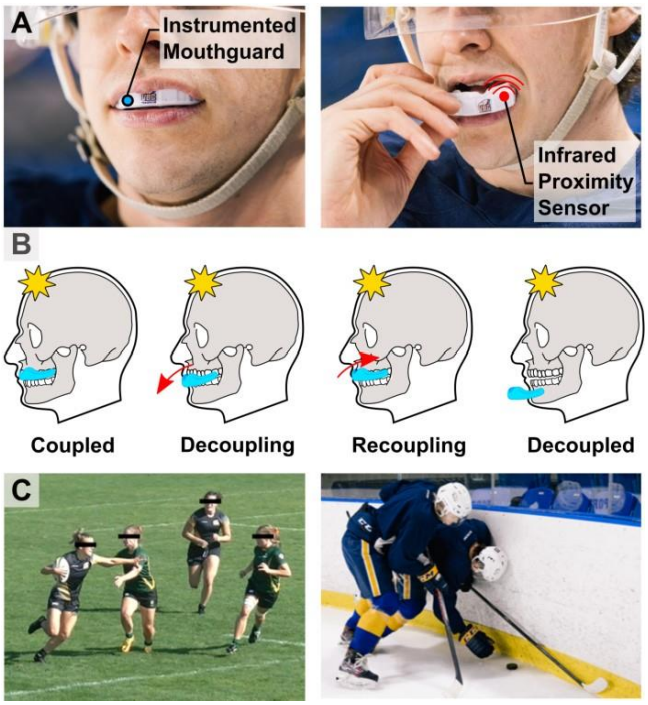

Figure 1: Study overview. Instrumented mouthguards (iMGs) contain proximity sensors to measure coupling with the upper dentition (A). iMG coupling during a head acceleration event (HAE) can be described with pre- and post acceleration event recording coupling states (B). Deployment of iMGs with athletes allows for the effects of coupling on HAE kinematics signal characteristics to be investigated (C)

Methodology: Forty-two university-level men's ice hockey (n = 21) and women's rugby (n = 21) athletes participated in the study, wearing iMGs during 6–7 month in-season periods. Each iMG contains a triaxial accelerometer and a triaxial gyroscope to record HAE kinematics, as well as an IR proximity sensor to assess device coupling (Fig. 1A). Proximity data classified video-verified HAE recordings into four main iMG coupling categories: coupled (on-teeth), decoupling (on-teeth to off-teeth), recoupling (off-teeth to on-teeth) and decoupled (off-teeth) (Fig. 1B). We assessed and compared HAE coupling categories for video-confirmed true positive and false positive women's rugby and men's hockey HAEs (Fig. 1C).

Results: We compared peak kinematics across coupling categories and found significantly higher angular accelerations ($p < 0.001$) in decoupling/recoupling/decoupled HAEs compared with coupled HAEs. In addition, when we compare frequency characteristics, decoupling, recoupling, and decoupled HAEs have significantly higher medium and high-frequency linear ($p < 0.005$) and angular acceleration ($p < 0.001$) band power compared with coupled HAEs (Fig. 2). Further, even video-verified true positives included poorly-coupled HAEs, and iMG coupling patterns varied between the men's hockey and women's rugby teams.

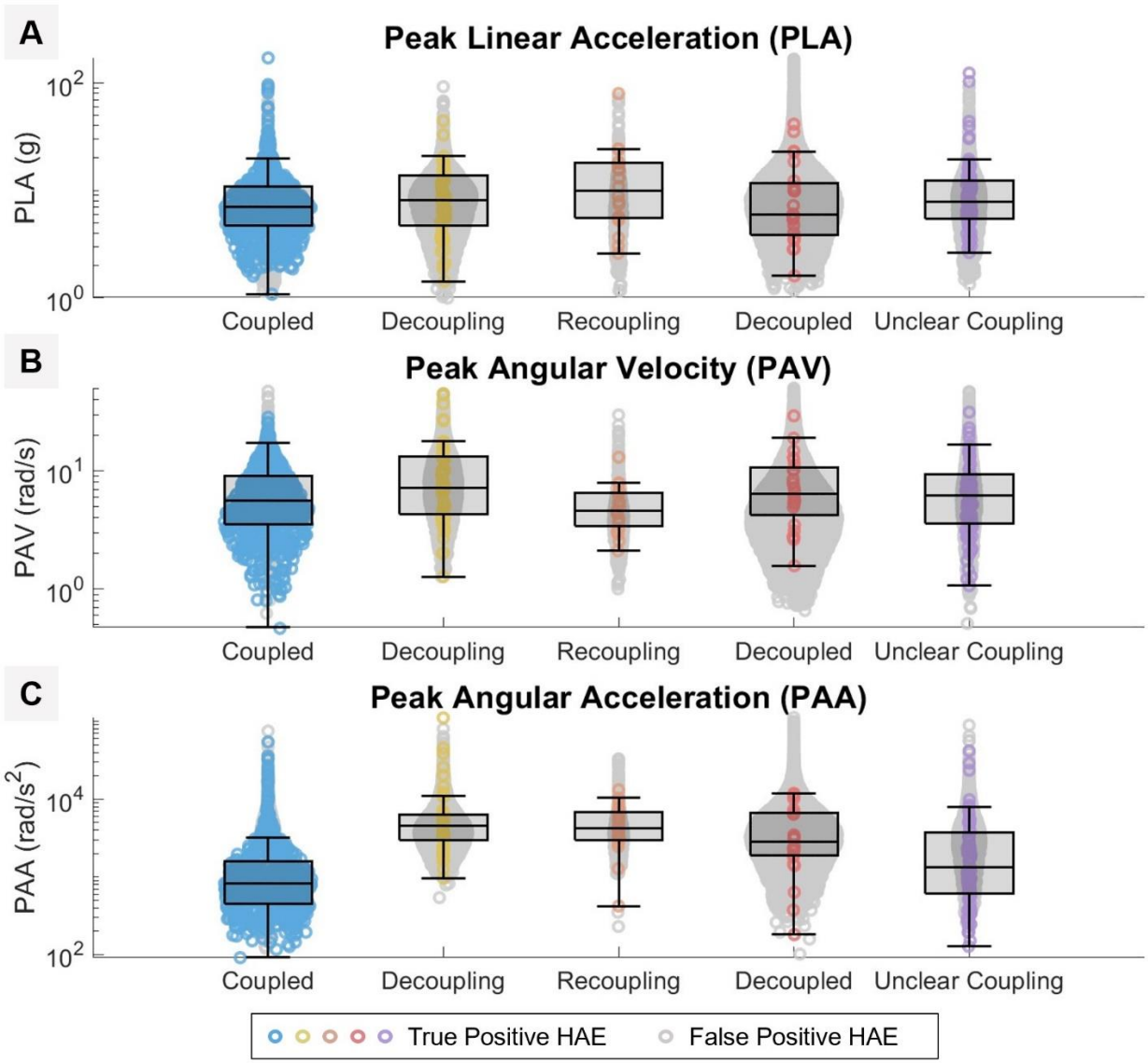

Figure 2: Peak kinematics for video-verified true positive head acceleration events (HAE) by coupling category. Box chart represents kinematics statistics of true positive HAEs, including (A) peak linear acceleration (PLA), (B) peak angular velocity (PAV), and (C) peak angular acceleration (PAA).

Discussion: In this study, we conducted a novel investigation of on-field iMG coupling using proximity sensor data. We developed and verified a thresholding method to determine on-field mouthguard coupling categories using proximity data clustering. The coupled category represents the desired mouthguard state for accurately recording skull kinematics during HAEs, while the other categories (recoupling/decoupling/decoupled) have a higher likelihood of being associated with sensor coupling errors. Our findings show the potential of using proximity sensing in iMGs to identify poorly-coupled HAEs. Utilizing this data screening process in conjunction with video review may mitigate a key source of sensor noise and enhance the overall quality of on-field sports HAE datasets.

References:

[1] - Mainwaring, L., Mylabathula, S., Pennock, K. F., Alavie, B. Z., 2018. Subconcussive head impacts in sport: a systematic review of the evidence. International Journal of Psychophysiology, 132, 39–54.

[2] - Tarnutzer, A. A., Straumann, D., Brugger, P., Feddermann-Demont, N., 2017. Persistent effects of playing football and associated (subconcussive) head trauma on brain structure and function: a systematic review of the literature. British Journal of Sports Medicine, 51, 1592–1604.

[3] - Wu, L. C., Nangia, V., Bui, K., Hammoor, B., Kurt, M., Hernandez, F., Kuo, C., Camarillo, D. B., 2016. In vivo evaluation of wearable head impact sensors. Annals of Biomedical Engineering, 44, 1234–1245.

[4] - Wu, L. C., Zarnescu, L., Nangia, V., Cam, B., Camarillo, D. B., 2014. A head impact detection system using SVM classification and proximity sensing in an instrumented mouthguard. IEEE Transactions on Bio-Medical Engineering, 61, 2659–2668.