Investigating Changes in On-Field Instrumented Mouthguard Coupling Over Time

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I. INTRODUCTION

Head acceleration event (HAE) exposure in sports poses risks for both acute and cumulative brain injury in athletes. Instrumented mouthguard (iMG) sensors are applied increasingly to quantify HAE exposure and biomechanics in sports [1]. Prior studies have shown that custom-formed iMG sensors worn on the upper dentition may couple more tightly to the skull than sensors mounted on skin or headgear and provide more reliable estimates of skull kinematics [2]. However, iMG validation studies typically simulate a tightly clenched coupling condition [3], which may be idealistic for tight skull coupling but it is unclear whether iMG sensors would have similar coupling on the field. This uncertainty makes it difficult to ensure that the in-lab kinematic accuracy findings can be expected of field data. In addition, athletic mouthguards are constructed using soft ethyl vinyl acetate material, which is prone to wear-and-tear over long-term use, especially if frequently chewed on.

Our recent work demonstrated the use of iMG-teeth proximity sensing in determining on-field sensor coupling status during HAE recordings [4], which is built on our prior laboratory validation of proximity sensing of skull coupling [5]. In on-field data, we found statistically significant HAE kinematics distributions for well-coupled versus poorly-coupled iMGs, where kinematic features often associated with noise (e.g., high-frequency content) are more pronounced in poorly-coupled HAE recordings. In the current short communication, our objective is to further quantify iMG coupling over time using proximity sensor data.

II. METHODS

Data Collection and Instrumentation

We recruited 21 university men's ice hockey athletes (University of British Columbia Research Ethics Protocol H21-00400) and 21 university women's rugby athletes (H21-03824) and gathered HAE data over a period of six-seven months during regular varsity season. Informed consent was obtained from all participants, and we adhered to the Declaration of Helsinki in all study procedures. Athletes were instructed to wear custom-formed Prevent Biometrics iMG sensors during both games and practices, with an average game compliance rate of over 90% and practice compliance rate less than 50%. The iMG was set up to record 50ms of six-degree-of-freedom kinematics using an 8g per-axis linear acceleration trigger. Along with the kinematics data, an infrared sensor measured the proximity between the iMG and teeth, recording 200 samples each time a potential HAE was triggered.

Proximity Data Analysis

Based on prior work [4-5], we can expect that proximity data from iMG sensors typically follow a bimodal distribution with distinct points clustered separately at high-proximity (on-teeth) and low-proximity (off-teeth) values. We expect potential changes in the proximity values associated with on-teeth clusters due to iMG wear-and-tear over time affecting mouthguard fit to the teeth. To examine this, we isolated iMG sensors that were worn and used for at least 20 practice or game days. Then, for days with at least 2000 proximity samples available for clustering analysis, we applied k-means clustering using k=2 to quantify the low- and high-proximity cluster centroids assumed to correspond to off-teeth and on-teeth clusters, respectively. The degree of successful clustering was quantified using an average silhouette score, and days with a score of over 0.9 were identified as having clear clusters. From the cluster centroids, we evaluated how the on-teeth proximity centroid changed over time for different iMGs using linear mixed effects models with time as a fixed variable and device ID as a random variable.

III. RESULTS

In total, we gathered data from 162 unique iMGs, noting that each athlete may have worn multiple iMGs over the data collection period due to device failure and replacement. Among the 162 iMGs, we identified 35 sensors worn for at least 20 practices or games, which had a median of 12 days (interquartile range 8-19 days) with at

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least 2000 proximity samples for clustering analysis. Using clustering analysis, we categorised 17 iMGs as having unclear coupling due to frequent low silhouette scores below 0.9. Among the remaining 18 iMGs, which more consistently clustered into two distinct proximity clusters on each day, 5 iMGs showed clear decreasing on-teeth cluster centroids, with a linear mixed effects model showing a statistically significant negative correlation between the on-teeth centroid location and use time ($p < 0.00001$) as well as device ID being a significant random effect. The other 13 iMGs showed stable on-teeth and off-teeth centroids, and the linear mixed effects model identified no significant correlations between on-teeth centroid location and time. The iMGs showing significant time change were categorised into a wear-and-tear (WT) group and those showing consistent clusters were categorised as stable (ST). As shown in Figure 1, an example ST iMG had on-teeth and off-teeth centroids of 1016 and 307 at the beginning of use (green early distribution), and 1018 and 318 at the end of use (orange late distribution); while for an example WT iMG, the on-teeth centroid decreased from 843 to 559.

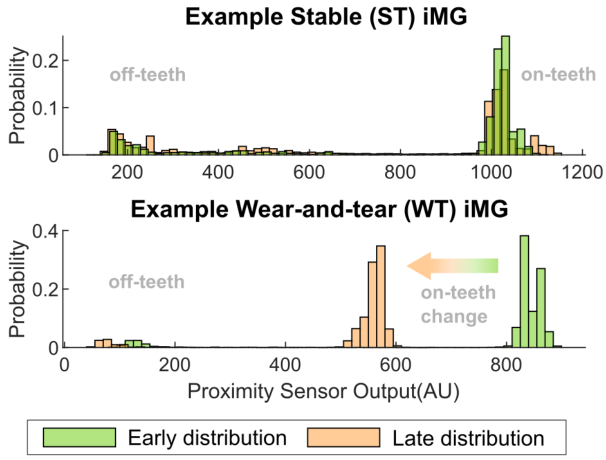

Fig. 1. iMG on/off-teeth cluster distribution over time comparing a stable versus wear-and-tear device.

IV. DISCUSSION

Tight coupling of instrumented mouthguard (iMG) sensors is critical to ensure the accuracy of skull kinematics recordings during head acceleration events. Our preliminary results show that some iMG sensors may gradually deteriorate due to usage over time. Changes in the on-teeth and off-teeth distributions of proximity values could indicate changes in the shape of the mouthguard due to wear-and-tear, where we expect to see that a loose-fitting mouthguard (e.g., due to material deformation over time) will have lower proximity readings (i.e., greater distance between iMG and teeth) even when the mouthguard is worn on teeth. Such loose-fitting mouthguards may lose their ability to provide sufficient skull coupling and potentially exhibit higher kinematic noise. Since we only identified this trend in 5 of 18 mouthguards with clear proximity clusters, it is possible individual athlete behaviour and habits (e.g., chewing) can affect device wear-and-tear. Another point of concern is that nearly half of the iMGs we examined showed unclear coupling without clear on/off-teeth states, which requires further investigation of whether these mouthguards can be tightly coupled to teeth in on-field settings.

Since this work investigated coupling patterns on a day-by-day basis, and we identified significant individual device variations in the proximity changes, we did not have sufficient sample size to compare changes in recorded HAE kinematics with statistical power. With accumulation of additional data over our longitudinal field studies, future work will aim to quantify, more directly, the effect of device wear-and-tear on kinematic accuracy. There is a potential to use proximity distributions for determining when a device may no longer enable sufficient coupling and needs to be replaced. This line of work contributes to improving quality screening of on-field HAE exposure measurements.

V. REFERENCES

[1] Hernandez F. *et al.*, Ann. Biomed. Eng., 2015.
[2] Wu L.C. *et al.* Ann. Biomed. Eng., 2016.
[3] Gabler L. *et al.,* Ann. Biomed. Eng., 2022.
[4] Luke D. *et al.,* J. Biomech., 2024.
[5] Wu L.C. *et al.,* IEEE Trans. Biomed. Eng., 2014.