Engineering Characteristics of Athlete Head Impacts that Cause "Obvious Performance Decrement" (OPD)

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I. INTRODUCTION

Over 50 million athletes in the United States participate in contact sports, and hundreds of thousands to millions sustain concussions annually. Roughly 50% of concussed athletes go unidentified [1]. Continuing to play for only *15 minutes* after a concussive blow causes recovery time to more than double [2]. The past decade has seen intense investigation into the accuracy and debate about clinical utility of head impact monitoring systems. A seminal paper by Mihalik and Guskiewicz reviewed American football helmet sensor and clinical data, concluding that *"a concussive injury threshold is elusive"* [3]. In 2014 the Institute of Medicine concluded that "*there are currently inadequate data to define thresholds specifically associated with concussions"* [4]. More recently, authors have advocated for lower uncertainty data: "*… accurate measures of individual exposure will yield a direct estimate of the human tolerance*"[5], "*… as more accurate sensors are designed …*" [6] "*… valid methods of measuring the direction and severity of on-field head impacts are needed*" [7]. In this study, we began exploring whether lower uncertainty head impact measures will deliver more clarity on the single dose-response experience in athletes. We measured and video-verified head impacts using an impact monitoring system embedded in an athletics mouthguard. Any single impact leading to "Obvious Performance Decrement" (OPD) on video was noted and its magnitude was compared to previously published data [8-10].

II. METHODS

Research methods were approved by a local IRB. We used a laboratory-calibrated impact monitoring mouthguard (IMM) system (Prevent Biometrics, Minneapolis, MN, USA) to measure head impacts and inertial motions in n=83 high school and college American football players over 269 athlete-days in the autumn of 2019. Head impacts meant time traces of physically realistic head kinematics in tandem with time-synchronised video verification [11]. False Positives, e.g. data traces that were triggered from non-head impact activity, were discarded using the same video review methods. Any head impact where the player was observed with loss of consciousness, dizziness, apprehensiveness, slow-to-get-up, unnatural reaction and affected speed of movement was flagged as OPD.

Linear and angular, velocity and acceleration, six degree-of-freedom (6DOF) kinematic time traces were captured at 3200 Hz over 50 ms. From these time traces, peak linear acceleration (PLA), peak angular acceleration (PAA), peak linear velocity (PLV), peak angular velocity (PAV), kinetic energy transfer (KET) and impact location were computed.

III. INITIAL FINDINGS

Laboratory Calibrations

To calibrate the IMM system, it was tested independently at Virginia Tech University as part of the Sensor STAR Program in impacts from 25 g to 100 g to the front, front boss, rear boss and rear. The results fit a linear model of the form IMM=1.00*REF+0.2g, R^2=0.98 (see Fig. 1).

Video-verified Impacts

A total of n=2,323 head impacts were video-verified, yielding a left-centered distribution that matched historical data [8-10] (see Fig. 2). There were zero false-negatives identified on video. The measured PLA ranged from 2 g to 100 g and included inertial and minor impacts for PLA<20 g. Among impacts over 20 g, 65% were to the front, 23% were to the sides and 14% were to the back of the head, respectively. The top 1% of head impacts were in the ranges of PLA >50 g, PLV >4 m/s, PAA >4,000 rad/s^2, PAV >20 rad/s and KET >40 J.

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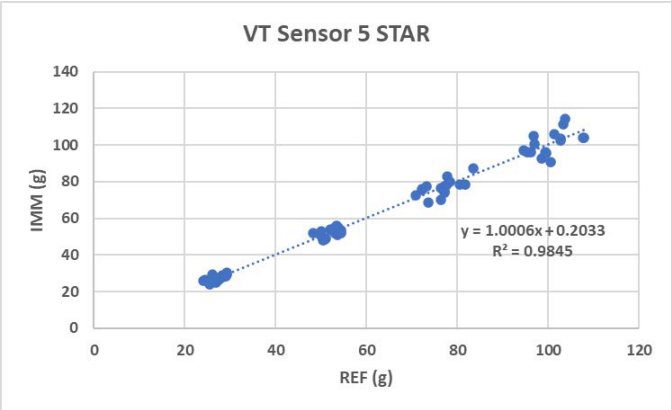

Fig. 1. IMM laboratory test results confirm data fit a linear model versus Reference.

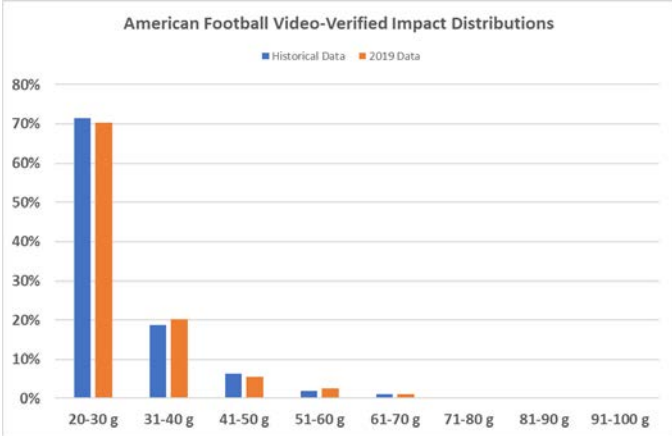

Fig. 2. IMM video-verified impacts from current study compared to published data [8-10].

OPD Impacts

Twelve of the top 15 (12/15, 80%) side- and rear-impact events (PLA range 40 g to 100 g, KET range 40 J to 120 J) resulted in OPD behaviour. One of the top 15 (1/15, 7%) frontal impact events (PLA range 35 g to 62 g, KET range 25 J to 64 J) resulted in OPD. The relationship between OPD impact magnitude and direction was comparable with previous data from [8-10] (see Fig. 3 and Fig. 4).

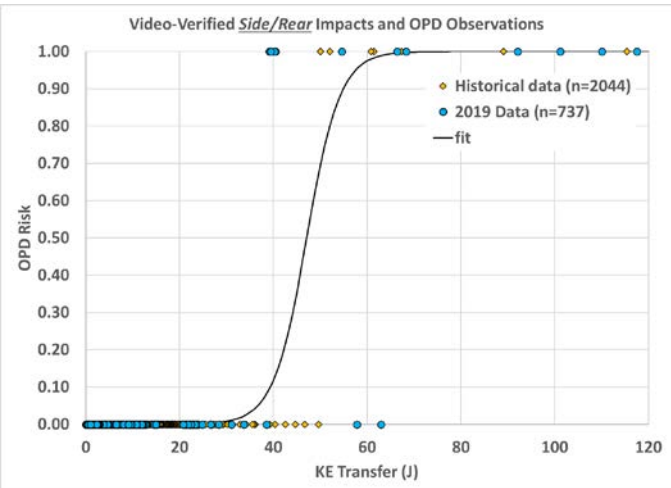

Fig. 3. Video-verified impacts for side/rear compared to published data [8-10].

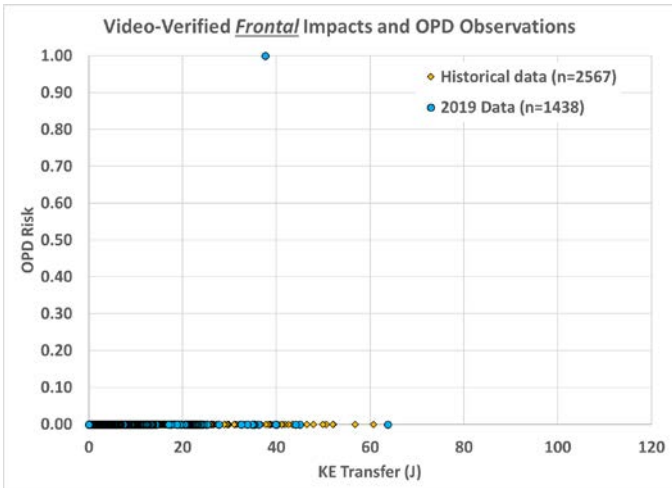

Fig. 4. Video-verified impacts for front compared to published data [8-10].

IV. DISCUSSION

Using a laboratory-calibrated IMM system, we video-verified head impacts in n=83 American football players over 269 athlete-days. A total of 2,323 impacts were verified, with 465 having PLA greater than 20 g. We found that head impact distributions from 2019 mimicked published data [8-10]. The KET range of previously published data on OPD events was similar to this study. We also found that OPD impacts occurred mostly to the rear and side of the head, which aligns with published data from IMM and predictions of others [12-14].

It is unclear why high-energy impacts to the side and rear have OPD behaviour more than frontal impacts. It could be that post-impact OPD behaviour possesses a directional sensitivity. We will continue adding to these data to more clearly define single-impact types that cause OPD behaviour, verify video with inter- and intra-rater testing as well as investigate cumulative impact relationships to OPD and objective clinical findings.

V. ACKNOWLEDGEMENTS

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VI. References

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