A Concussion Threshold is Emerging in the Top 1% of Head Impacts in the Military and Athletes

Adam Bartsch

I. INTRODUCTION

Researchers have been unable to reliably link head impact time traces, video of an impact, and concussion. Leading clinicians have gone so far as to declare data from helmet sensors to be 'clinical irrelevant' [1]. More recent data [2-6] have confirmed that impact monitoring mouthguard (IMM) sensors are capable of reporting head centre of gravity (CG) kinematics within 5–10% of truth. This is contrasted with earlier sensors shown to have upwards of 300% error [7]. On the playing field, mouthguard sensors have also been shown to: (1) collect head acceleration event (HAE) data when on the teeth [8]; (2) correlate closely with video review of collisions [9]; and (3) report HAE magnitudes for direct and inertial loading in the ranges of laboratory calibrations [6]. This paper outlines data from an accurate head IMM that confirm a clear dose-response relationship for impacts in the top 1% by magnitude, versus concussion signs, and concussion.

II. METHODS

Data were collected on 973 subjects who wore the IMM (Prevent Biometrics, Minneapolis, MN, USA) over 3,449 subject-days. The IMM has been extensively calibrated in the laboratory and on the playing field [3-6][10]. A variety of military and civilian activities were studied, and ethics approval was obtained for each activity. Military training, including parachute, hand-to-hand combat and athletics, along with civilian American football, hand-to-hand combat, ice hockey and rugby are represented here. A total of 54,602 HAEs were analyzed using processing methods reported in-depth elsewhere [8]. Video verification, on-teeth hardware and time trace analysis were all used to confirm HAE versus non-HAE data. Visible concussion signs [11] were documented using the same methods as all major sporting bodies. These collisions, where at least one visible concussion sign was seen on video within 30 s of impact, are 'check engine' impacts. All 'check engine' impacts had their raw (at tooth) and head CG time traces examined for head impact frequency content of 20–80 Hz [12], and the impact direction/location was confirmed against the video. The 'check engine' impact magnitude was qualitatively checked as well, to confirm whether the impact on video was Large, Medium, or Small. The SIMon finite element model [13] was used to estimate internal brain strains in concussion impacts.

III. INITIAL FINDINGS

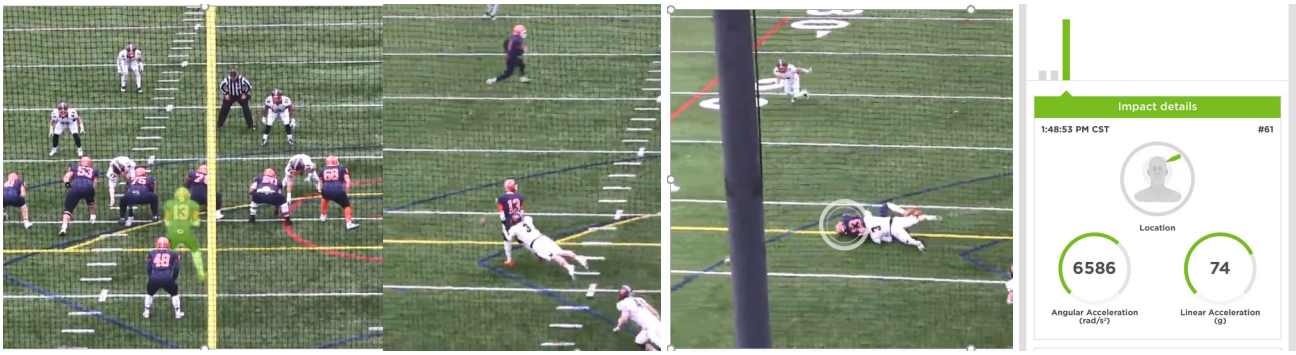

Fig. 1. The 'check engine' HAEs involve significantly higher energy and momentum transfer on video, with subjects often displaying concussion signs and transient loss of consciousness.

In Fig. 2 the head impact distributions are shown, as well as individual peak values. There were 17,551 HAEs measuring >10 g. The median impact, 14 g, was on the high end of the activities of daily living (ADL) range. There were n=124 impacts between 50 g and 100 g PLA (0.7%).

A .Bartsch works for Prevent Prevent Biometrics, Minneapolis, MN, USA.

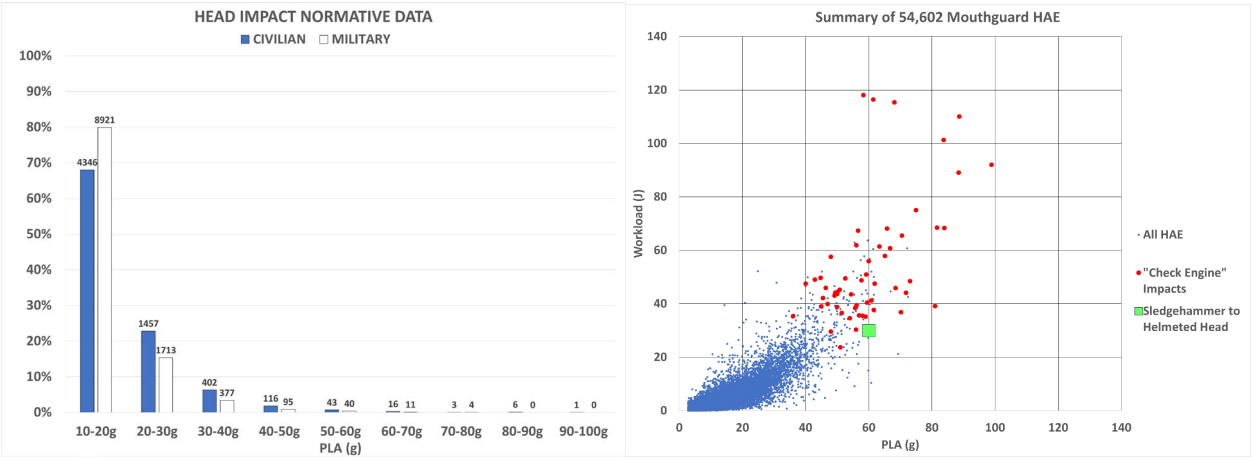

Fig. 2. Distributions for CG PLA >10 g in civilian and military subjects (left), and all peak values (right). Less than 1% of all head impacts were between 50 g and 100 g. The n=57 'check engine' impacts are shown in large, filled circles. For reference, a sledgehammer hit to a helmeted ATD is also shown (solid square).

The median 'check engine' impact was 58 g and 46 J. All 57 'check engine' events had physically realistic time traces, were Large or Medium impacts on video, and in the top 1% by magnitude of PLA, in the top 1% of Workload, or both. There were 18 concussion-causing 'check engine' impacts, and 39 'check engine' impacts where the concussion assessment information was unavailable, or a concussion assessment was not conducted. The concussion HAEs were simulated using SIMon. None of the HAE had a CSDM 0.25 level above the critical level of 0.54, or above the MPS critical level of 0.87 [13].

IV. DISCUSSION

This paper reports on 54,602 HAEs from 973 military service members and civilians who wore an instrumented mouthguard. In total, 92% of HAEs were within ADL ranges. In military subjects, the preponderance of low-gravity HAE was due to the high rate of combative grappling manoeuvres, light head contact (boxing, combatives, American football, rugby), parachute deployment (static and freefall) and parachute landing falls (PLF). In civilians, evasive manoeuvres (boxing, mixed martial arts, karate), jumping/cutting during play (American football, ice hockey) and light contact were responsible for the low gravity HAEs. There were n=57 'check engine' head impacts with concussion signs; PLA ranged from 36 g to 99 g (median 58 g); and Workload ranged from 24 J to 118 J (median 46 J). All 'check engine' HAEs looked Large or Medium on video, and concussion signs presented within 1–30 s post-impact. These impacts were all in the top 1% by PLA, Workload, or both. The median 'check engine' impact PLA was on par with a sledgehammer hit to a helmeted crash test dummy head (60 g), with about 50% higher Workload (30 J). Eighteen 'check engine' HAEs were concussions and the other 39 had unknown diagnosis outcomes. The SIMon brain strains for concussion HAE fell well below theoretical injury limits for diffuse axonal injury despite the devastating nature of the impacts caught on video and the fact that many of the concussion impacts were within estimated National Football League (NFL) [14] concussion magnitudes. This paradoxical result could point to the need to vet the SIMon model more fully versus on-field data and clinical outcomes. These results may start to shift the thinking about the oft-debated concussion threshold. While these data do not conclusively define an injury threshold, they do confirm that the top 1% of HAEs is where all 'check engine' and concussion impacts resided. By knowing who is the most severely struck, precise and targeted concussion assessments should be feasible. And this, in turn, may reveal more precise and accurate correlations between concussion dose and response.

V. REFERENCES

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