Traumatic Brain Injury Predictions Amid Equestrian Activity with Realistic Biomechanical Constraints

W. Dawber, L. Foster, T. Senior, J. Hart

I. INTRODUCTION

9.7-15 % of all equestrian injuries are mild traumatic brain injuries (mTBI) such as concussion [1]. A study of severe equestrian related injuries (Injury Severity Score > 12) revealed that in 298 recorded incidents, 76% of all injuries were a result of the rider being thrown or falling from the horse and 48% were classified as head/brain injuries [2]. Laboratory, and test standard, replication of head impact scenarios typically use anthropometric headforms in isolation to predict injury severity, by measuring the heads kinetic response [3]. This is the adopted approach with published studies of equestrian rider falls to date. Clark et al (2020) used an angled rail impact system and Hybrid III headform in replication of rider fall, predicting translational and rotational accelerations of 89 g and 4000 rad·s^{-2} as 80% likelihood of sustaining mTBI [4]. Although such an approach creates easily repeatable methodology, it disregards other biomechanical constraints that affect both the response of the head and the injury sustained. Adoption of an approach that maintains the full realistic motion of the human body has not yet been explored, though would improve the understanding of actual conditions that result in TBI in this scenario. This approach could result in more representative test methodology, and improvement in efficacy of developed helmets.

II. METHODS

A procedure to recreate the fall of a rider from horseback has been developed, that captures the head kinematics with inclusion of full body biomechanics, for prediction of TBI. The horse is assumed in experiment to be stationary for simplicity and repeatability. Trials used a 77.7 kg bare 50th percentile male full-body Hybrid III anthropometric test device (ATD) that was positioned in a seated posture on a 1.73 m high platform; the largest expected height of a riding horse (Figure 2). A lateral load was applied to the shoulder joint of the ATD, causing the torso to roll from the platform and freely fall to the concrete floor. The surface was believed to produce a more severe injury than turf, while still relevant to road activity. The headform was equipped with a 100,000 Hz 3α3ω inertial sensor, at the CoM, to record translational and rotational kinematics. Data was processed with CFC 1000 and 180 4th order Butterworth filters in line with SAE J211 [5]. Injury criteria (IC) were adopted, alongside direct kinematic measurements, to predict injury severity using MATLAB script. HIC_{15} is derived from translational kinematics, while its current adoption within impact standards provides opportunity for comparing severity [6]. Additionally, RIC_{36} permits TBI predictions based on rotational kinematics, when used in conjunction with HIC_{15} [7]. BrIC is an alternative rotational predictor, derived from computer simulated brain deformations, and considers the directional sensitivity of the head [8]. Two high-speed cameras, positioned 4 m from the platform with 2000 Hz frame rate, captured the fall from the anterior and lateral views. Markers in plane with the headform centre of mass were tracked over 20 prior impact to measure velocity. In total, 23 repeated trials were conducted, in line with other studies exploring fall characteristics [4].

III. INITIAL FINDINGS

In all falls, the crown of the ATD struck the floor before any other body part. Mean impact velocity (V) was 4.91 ±0.32 ms^{-1}. Figure 1 shows the affected headform, neck and torso orientations at periods of contact and maximum neck deflection. Figure 3 demonstrates resultant acceleration for both translation and rotation. In each, a large pulse demonstrates rapid loading/unloading within 2.5 ms. Peak accelerations were 425 g and 7946 rad·s^{-2}. Peak linear acceleration (PLA) was in-line with studies using rigid mounted (PLA = 471 g) or unconstrained (PLA = 407 g) headforms, for similar impact velocities (ΔV = +0.48 ms^{-1}) [9-10]. Peak linear and rotational accelerations exceeded the 80 % mTBI threshold of Clark et al (2020) [4]. Translational measures consistently included an unloading period before peak, and a subsequent pulse significant for injury. Rotational measures unloaded to below 50 % of peak at 2 ms, then maintained longer than translational. The return to negligible load for translational was 6 ms, while rotational was 9 ms. Standard deviation brackets show translational variation was relatively less than rotational, though both were greatest at transitions between loading and unloading. Mean HIC = 2397 ±410 predicts 95 % probability of severe TBI (sTBI = AIS4+). RIC = 1.01E+07 ±6.64E+06 and BrIC = 0.24 ±0.10, respectively predict a 50 % and 10 % probability of mTBI [11].

W. Dawber is a PhD student in Engineering at Sheffield Hallam University in United Kingdom (w.dawber@shu.ac.uk, 0114 225 3399).
J. Hart is Dr of Engineering in the Health Research Institute at Sheffield Hallam University in the United Kingdom.

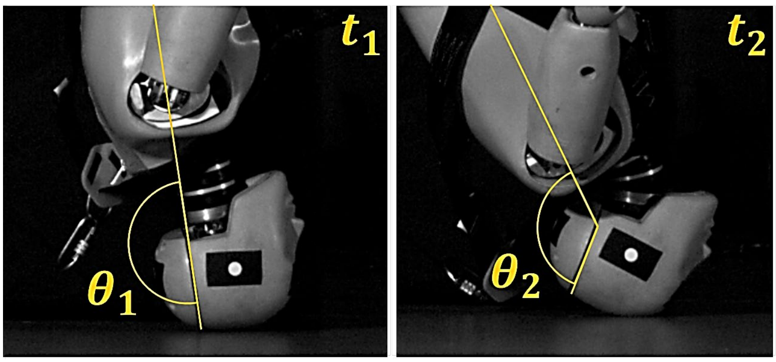

Figure 1. Example high speed video frames at contact (t_1 = 0 ms) and maximum neck deflection (t_2 = 50.5 ms). Orientation change of headform/torso = -45.4° ($\Delta\theta$).

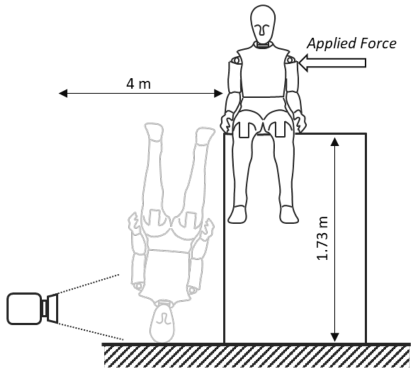

Figure 2, Anterior view of ATD at riding horse height (1.73 m). Location of applied load, lateral view camera and ATD orientation at impact illustrated.

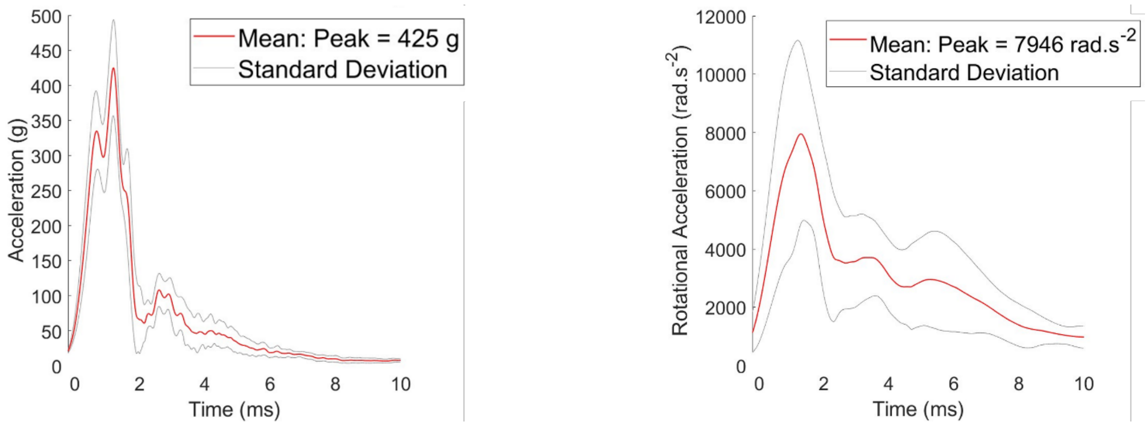

Figure 3. Mean translational and rotational acceleration curves, with plotted standard deviation bands and peak values.

IV. DISCUSSION

Initial findings provide a baseline of sustained injury when falling from horseback, which can inform development of test methodology for equestrian headgear. This is done without discarding biomechanical constraints that affect the response of the head, at the hinderance of repeatability. Demonstrated is the visual and quantitative impact response of the headform. This phenomenon with full-body biomechanical constraints has not been explored to date in mechanical-based study with equestrian application. The test method in this study prioritised representativity over repeatability and produced large variation in results. Rotational motion occurred because body mass and neck deflection induced torque in the headform. This would not occur with a rigid test rig. Likewise, a crown impact using an unconstrained headform would bounce, similarly to a ball, and rotate by its own distribution of mass. Therefore, the inclusion of systems to permit realistic headform rotation in test methods, such as the Hybrid III articulated neck, is an important adoption when considering rotational kinematics for injury predictions. Disagreement of injury predictions between BrIC and that of Clark et al (2020), which is based on in-field injury, suggests BrIC may not be suitable for this method where rotational kinematics are not the dominant factor for injury severity. It is hypothesised that falls from a galloping horse would impart greater tangential load on the headform and produce greater injury predictions from rotational based IC. The extension of the study to include a moving platform and alternative impact surfaces, such as turf and sand, would broader represent equestrian activity. Additionally, injury predictions using Finite Element (FE) simulation and modern IC, such as DAMAGE which suggests marginally higher correlation with TBI, would strengthen injury severity understandings [12].

V. REFERENCES

[1] Zuckerman S et al, World Neurosurg, 2015
[2] Ball J et al, J Trauma Manag Outcomes, 2009
[3] ASTM F1163, 2023
[4] Clark J, J Sci Med Sport, 2020
[5] SAE J211, 2022
[6] Versace J, Stapp Car Crash, 1971
[7] Kimpara H et al, Ann Biomed Eng, 2012
[8] Takhounts E et al, Stapp Car Crash J, 2013
[9] Cripton P, Accid Anal Prev, 2014
[10] Shields B, J Athl Train, 2009
[11] Hayes W, Annu Rev Biomed Eng, 2007
[12] Gabler L et al, Ann Biomed Eng, 2019