Evaluation of *WaveCel* Helmets Using HIII Head and Neck in Oblique Impacts

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I. INTRODUCTION

In cycling, the majority of helmet standards assess helmet performance by relying solely on linear kinematics, lagging behind the wealth of research supporting the inclusion of rotational kinematics as a key contributor to brain injury [1]. Many recently commercialized helmets are now equipped with components explicitly designed to mitigate rotational energies. As such, further investigation into how well these innovations combat rotational and linear energies as a complete helmet system is warranted. In this study, we investigated the effectiveness of a commercially available helmet equipped with a second-generation version of the *WaveCel* liner aimed to mitigate head injuries by reducing both linear and rotational head accelerations. A series of frontal-oblique head impact tests were carried out to compare the *WaveCel*-equipped helmets to two standard expanded polystyrene (EPS) helmets.

II. METHODS

Helmets & Test Conditions

A helmet model (*Bontrager Rally*) equipped with *WaveCel* was tested against two control helmets equipped with only EPS: the commercially available *POC Tectal* and a modified version of the *Bontrager Rally* – where the *WaveCel* layer was substituted by a layer of equally thick EPS. The three helmet types were tested across four different frontal-oblique impact conditions (n=5 helmets per test condition per helmet type): 'slow' impact velocity of 4.8 m/s ± 3% with impact platen angled at 30°, 45° and 60° from horizontal ('S30'/ 'S45'/ 'S60'), and 'fast' impact velocity of 6.2 m/s ± 3% with platen angled at 45° ('F45').

Test Setup

Tests were conducted using a guided drop carriage equipped with a Hybrid III 50th Percentile Male (HIII-50M) head-and-neck surrogate. The carriage travelled along an I-beam during each drop (Fig. 1) and the head impacted onto an angled platen lined with 80-grit sandpaper. The HIII-50M head was lined with double layers of nylon stocking to mimic hair friction. The headform was instrumented with a nine-accelerometer array package collected at 10 kHz and filtered at Channel Frequency Class 1000.

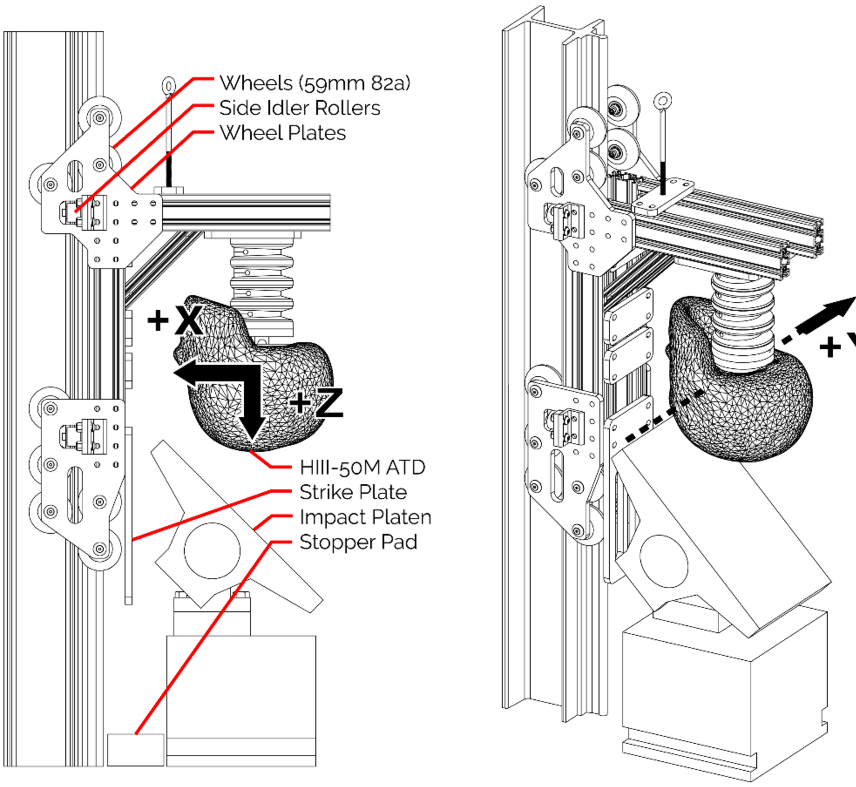

Fig. 1. The 14.0 kg drop carriage.

Data Analysis

The first 20 ms of post-trigger data was used to exclude any deceleration caused by the strike

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plate contacting a stopper pad (Fig. 1), the function of which was to interrupt tests where the neck was forced into large extension angles. To evaluate head kinematics, we calculated peak resultant linear acceleration (PLA_R), peak rotational velocity about the y-axis (PRV_y) and peak rotational acceleration about the y-axis (PRA_y).

When identifying PRV_y and PRA_y, earlier studies have either used absolute single-axis magnitudes [2] or resultant measures [3], which are unsigned by definition. In this study, only positive single-axis values were used to identify PRV_y in order to exclude the elastic response of the HIII-50M neck as the head rebounded into extension (i.e. negative rotational velocity) following the initial flexion phase induced upon impact [2-3]. For peak PRA_y, absolute values were used. To evaluate the probability of head injury, we reported the National Highway Traffic Safety Administration (NHTSA) 15 ms Head Injury Criterion (HIC15) [4] and the probability of sustaining brain injuries with an Abbreviated Injury Score of 2 (AIS2) based on the Brain Injury Criteria (BrIC) calculated from PRV_y [5].

To test the null hypothesis that the *WaveCel* type helmet 'W' offered similar kinematic and head injury outcomes as the *POC Tectal* 'P' and EPS analogue 'E', two-sided student t-tests was conducted for each test scenario, comparing 'W' vs 'P' and 'W' vs 'E'. Bonferroni correction for the two comparisons was made, thus adjusting the p-value threshold for statistical significance from 0.05 to 0.025.

III. INITIAL FINDINGS

Initial findings showed that *WaveCel* exhibited statistically significant reductions in the probability of AIS2 head injury and PRV_y across all test comparisons. The 'W' group reduced P(AIS2) by 8–37% compared to 'P' group and by 3–36% when compared to 'E' group, with the largest improvements observed in the F45 test series. 'W' helmets also showed significant reductions (21–39%) in HIC15 when compared to 'E' helmets for all tests. When compared to 'P' helmets, 'W' reduced HIC15 by 7–18% across slow impact tests, but did not show a statistically significant improvement in the F45 tests.

In all tests we observed, first, a head flexion phase, followed by a secondary head extension phase. The extension phase of the impact at times corresponded to rotational accelerations and velocities that were greater in magnitude than that from the initial impact (flexion) phase. However, the extension phase was concluded to be an artefact of the energy stored in the HIII neckform during the neck flexion in the initial impact phase; it was excluded from analysis as previous authors have also done [3]. The conclusion that this 'snap back' response lacked biofidelity was further supported by a computational study by Ghajari *et al*., where a human body model was tested in frontal-lateral oblique head impacts [6] and the resulting head rotational acceleration upon rebound was only ~30–40% of the initial impact-related head acceleration. Furthermore, Nightingale *et al*. [7] performed cadaveric frontal-oblique head impacts onto a 15° platen and observed no energetic spine rebound of the kind seen in our HIII-50M tests. Therefore, on balance it remains questionable whether the kinematic response of the head exhibits sufficient biofidelity once the HIII neck begins to rebound into extension.

IV. DISCUSSION

Bontrager Rally WaveCel helmets significantly reduced linear acceleration, rotational acceleration and rotational velocity in most of the test conditions in this study. The test conditions included axial and tangential impact components and were representative of real-world 'over-the-handlebars' cycling collisions. These promising results of the *WaveCel* technology should be further confirmed through additional laboratory studies using other impact points, and also through real-world mountain biking and road cycling injury statistics.

V. REFERENCES

[1] Fahlstedt, M., *et al*., *Ann Biomed Eng*, 2021.
[2] Hansen, K., *et al*., *Accid Anal Prev*, 2013.
[3] Bland, M., *et al*., IRCOBI, 2018.
[4] Eppinger, R., *et al*., NHTSA, 1999.
[5] Takhounts, E. G., *et al*., *Stapp Car Crash J*, 2013.
[6] Ghajari, M., *et al*., *Accid Anal Prev*, 2013.
[7] Nightingale, R. W., *et al*., *J Biomech*, 1996.