An Assessment of a Body-first Test Rig in Comparison with Head Kinematics from Hybrid III Dummy Experiments and Human Body Model Simulations

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I. INTRODUCTION

Falls are a major cause of head injury, both in leisure and work-related accidents. Independent of whether the fall is mainly vertical or has a large horizontal component, the literature indicates that in most cases another body part than the head impacts the ground first [1–3]. This initial impact will affect the kinematics of the head both pre- and post-impact. These types of impacts may be termed body first. To design and assess head protection, especially with focus on rotational head kinematics, the influence of body-first impacts needs to be better understood. To replicate the kinematics in body-first impacts, different experimental test setups have been assessed since there is no standard setup recommendation [4–5]. There are limitations in using isolated neck surrogates like Hybrid III (HIII) when replicating head impacts [6]. However, using a complete HIII dummy is heavy, time consuming and most importantly the fall behavior is not repeatable dismissing the method for comparison of different helmet designs. The purpose of this study was to evaluate the head kinematics from a newly designed body-first test rig compared to both HIII dummy experiments and simulations with a Human body model (HBM).

II. METHODS

This study looked at the head kinematics from three different assessment methods: a body-first impact test rig, experimental HIII dummy back falls, and numerical simulations with the HBM THUMS.

Body-first Test Rig Setup

A horizontal test rig was designed to mimic the head kinematics from HIII backward drop tests, replicating head kinematics before and at impact. The body-first test rig was constructed with a sled on a low friction rail with a 50th percentile HIII head and neck attached, Fig 1. Head kinematics were captured with a 6-degree-of-freedom (6DoF) sensor (DTS, CA) at centre of gravity (CG). The sled was accelerated by a pneumatic piston (A). To mimic the body impact with the ground the sled was decelerated by a pneumatic damper (B). The deceleration was controlled by varying the damper pressure pre- and post-impact. The anvil (C) was a metal plate adjustable in height and tilt. The position of the decelerator and anvil were adjustable individually and the accelerating piston had a stroke length of 0–60 cm. The variability in the rig setup allowed many variations in head kinematics. In this study the sled accelerated to 4.1 m/s before impact.

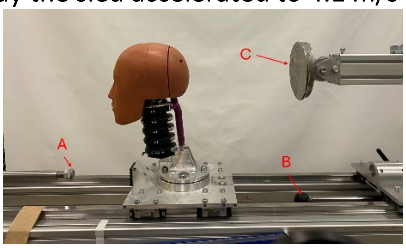

Fig 1. Body first test rig setup. A: accelerator piston, B: decelerator piston (damper), C: anvil


Fig 2. HIII dummy positioned for drop test

Fig 3. Thums model positioned for impact (30°).

Experimental Testing with HIII dummy

To ensure that the rig replicated the behavior of a complete HIII dummy, a series of 10 drops both with and without a helmet were performed (HIII drops). The focus was on the kinematics before impact, where the helmets' influence was considered negligible. The dummy was dropped from a height of 1.0 meter measured from ground to the most proximal surface of the dummy (glutes), positioned with both legs and back angled ~30° from horizontal, using two wires attached to the ankles and a fall arrest harness, Fig. 2. The head was

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instrumented with a 9-accelerometer array giving 6DoF accelerations using [7]. The kinematics was used to create a corridor based on its maximum and minimum values over time.

Computational Modeling with THUMS HBM

To ensure that the motion captured by the HIII was not only due to the stiff spine of the dummy, numerical simulations were also performed with a more biofidelic HBM in LS-Dyna. The THUMS AM50 v4.1 occupant model [8] was positioned by rotation in the sagittal plane, until the back was at an angle of 30° (rotated 55° from occupant position), Fig. 3, 25° and 20° respectively from the ground. An initial velocity of 4.1 m/s was applied to the body. Head kinematics were obtained from a node in the head CG.

III. INITIAL FINDINGS

The HIII drops showed a whiplash motion of the head and neck where the head rotated forward as the glutes impacted the ground, the flexion phase, then turned into an extension phase before impacting the ground, (HIII exp max/min in Fig. 4). The head angular velocity in the sagittal plane (AVy) from the body-first test rig (BF-rig) showed a similar behavior as the HIII drops, with a flexion phase as the sled accelerated and an extension phase when the sled was decelerated. The flexion phase of the BF-rig reached a similar peak AVy but over a longer duration whereas the extension phase was similar in both peak and duration. By altering the resistance of the damper, the extension phase could be adjusted in peak and duration (lowDec in Fig. 4). By moving the anvil closer, the time and thus the head position at impact was changed (anvilClose). By increasing the acceleration pressure, the peak flexion was increased as well as the peak extension (highAcc). The THUMS simulations resembled the HIII drop and matched the BF-rig kinematics in both magnitude and shape for the 30° impact, Fig. 5a. The two smaller angles relative to the ground (20°, 25°) resulted in smaller peak AVy in both flexion and extension but larger peak angular acceleration, Fig. 5b.

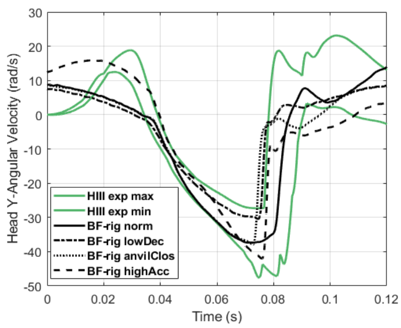

Fig 4. Head Y-angular velocity from the body-first test rig in four setups, and the corridors from HIII dummy drops.

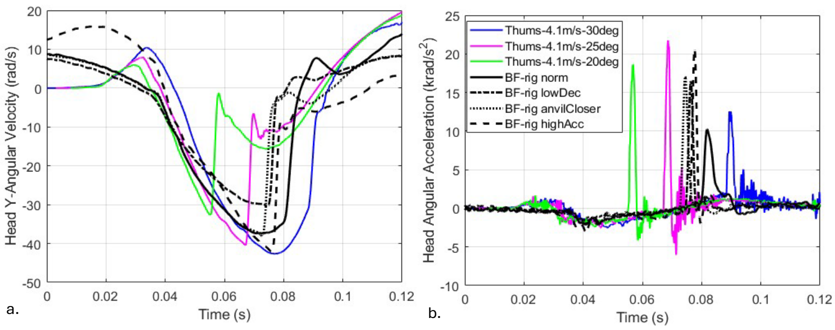

Fig 5. Head Y-angular velocity (a) and Y-angular acceleration (b) for Thums-simulations with three different back angles and experimental data from the body-first test rig with different setups.

IV. DISCUSSION

The head kinematics in a body-first impact is more complex than a direct head impact, with two distinct phases of initial rotation before head contact. This study has shown that even though there were differences in the setups with each studied model, the characteristic behavior was the same with a whiplash motion of the head and high angular velocity before impact. There were limitations in both experimental models, the HIII neck was not developed for this specific impact, and the neck was attached to either a relatively stiff spine (HIII drop) or a rigid plate (BF-rig). However, the THUMS model did not include muscle activation which might make it too compliant. This study focused on the extension phase just prior to head impact since that is when the impact occurs. However, more research is required to understand post-impact head kinematics and adjustments are needed to achieve a more realistic flexion phase. In the HIII drops and simulations, flexion resulted directly from the body impact, whereas in the BF-rig it resulted from acceleration in the initial boundary condition. Therefore, further research is needed to validate how the body and neck influence head kinematics and head injury prediction.

V. REFERENCES

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