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I. INTRODUCTION

Oblique impact can cause head trauma, such as diffuse axonal injuries and acute subdural hematoma. This paper focuses on the effect of oblique impact when wearing a bicycle helmet. Current helmet testing procedures focus only on measurements at the centre of gravity (CG) of the headform. This information might help in predicting the expected injuries in the brain, but it does not give any information about the kinematics of the head and the helmet that lead to those outcomes. Such information could help in improving helmet design and testing, possibly reducing the magnitude of the variables that lead to traumatic brain injuries. Experiments with cadavers and dummies have not produced conclusive results with regard to the effect on the neck, while the tightness of the straps on the headform is thought to increase its rotational acceleration. In terms of helmets currently being produced, the leading method of preventing rotational acceleration is internal sliding technologies. The questions that this paper seeks to address are: (1) How can we use motion-tracking techniques to assess the kinematics of a helmeted head impacting an oblique anvil? (2) Does the presence of a neck affect the functionality of the straps during testing? (3) Should a neckform be added to assess the effect of straps during tests against rotational acceleration? (4) How do internal sliding technologies affect the kinematics of the head during impact?

II. METHODS

During motion-tracking, predefined patterns, or signals, are detected in a series of video frames using image analysis techniques. The derived data can give information about the kinematics of that object. In our study, the freeware "Tracker" was used to track the motion of certain patterns on the head and helmets. All patterns on the head were on the same plane as the patterns on the helmet, with some deviations during impact due to the slide rotation of the system. These deviations can be considered negligible as the impact is almost perfectly symmetrical during the 10 ms of its duration, as shown by the graph of the angular velocity measured around the X and Z axes during the impact (Fig. 1). In addition, for rotation of less than 15^o around any random axis on the XZ plane, the error in measurement is also negligible. Figures 2 and 3 show the error between the seen angle for rotation and the initial angle of the tracked line.

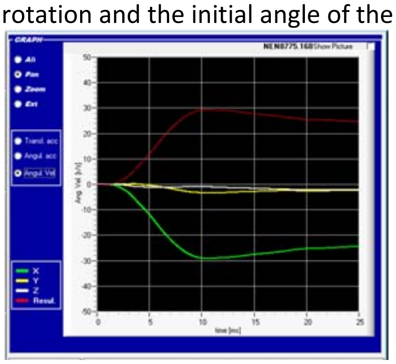

Fig. 1. Angular velocity measured during the impact. Negligible in Y and Z axes.

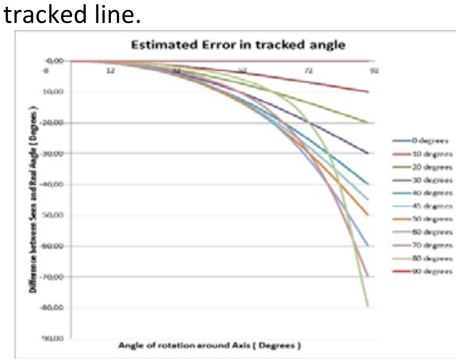

Fig. 2. Error in seen angle of a horizontal tracking line if 0–90^o inclination of axis of rotation is assumed.

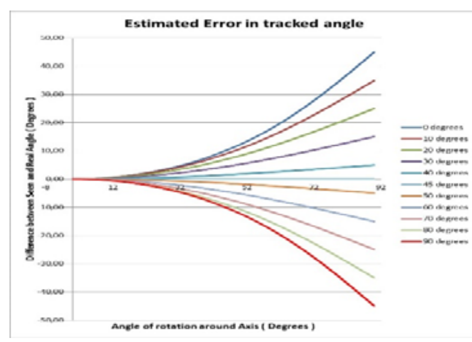

Fig. 3. Error in seen angle of a 45^o inclined tracking line if 0–90^o inclination of axis of rotation is assumed.

The technique is not limited to the pattern that will be used. The outputs of the technique were the relative angle between the head and the helmet, the rotation and the angular velocity of the head and the helmet. A series of ten (10) experiments were performed to examine the kinematics of a helmeted head. The set-up and testing process that were used were aligned with the work of [0]. HIII was chosen for its biofidelic moment of inertia around the tested axis of rotation [0]. A system of nine accelerometers was mounted inside the test head according to the 3-2-2-2 method described by Padgaonkar et al [0]. To assess the effect of the neck on the kinematics of the headform due to the straps, a cylindrical, lightweight cylinder was added to the headform's base to simulate a simple neckform. To assess the effect of a mechanisms against rotational acceleration on the kinematics of the headform, a commercially available product was used (MIPS). Two different LAZER helmet

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models of relatively round shape, were tested. A helmet with medium geometric complexity and a one of high geometric complexity. All experiments were recorded by a high speed camera with a frame rate of 3600 fps.

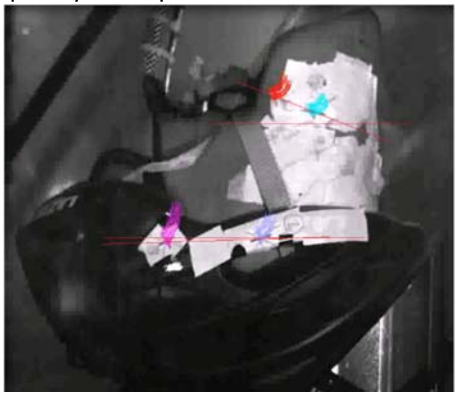

Fig. 6. Impact without neckform.

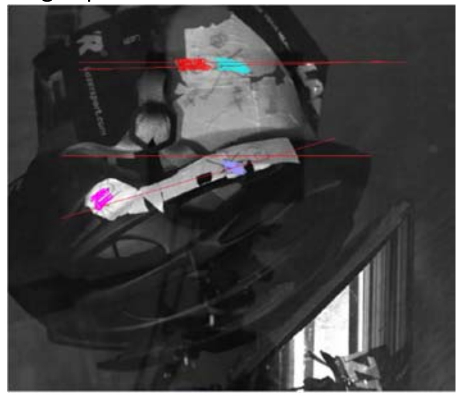

Fig. 7. Impact with neckform.

III. INITIAL FINDINGS

Results showed that the observed impacts can be broken down into four different stages (Figs 8-9). During the first stage, the helmet impacts the anvil, but the head keeps its translational motion. During the second stage, the head impacts the internal surface of the helmet and starts rotating. At the third stage, we reach the maximum angle between the helmet and the head, after which the helmet decelerates and the head keeps rotating with an almost constant pace. As far as the neckform is concerned, results showed that its existence did not affect the kinematics of the headform due to the restrictions created by the straps. This is probably a result of the first stage of the impact, during which enough space is created between the neck and the straps for the head to move freely, as if the straps do not exist. In the fourth stage, the existence of MIPS reduced the rotation of the headform up to 65%. The angular velocity of the headform, measured using motion-tracking, was validated by comparing it with the velocity measured by the accelerometers of the headform. As shown in Fig. 9, the results match and thus the technique can also be used to measure the angular velocity of the helmet.

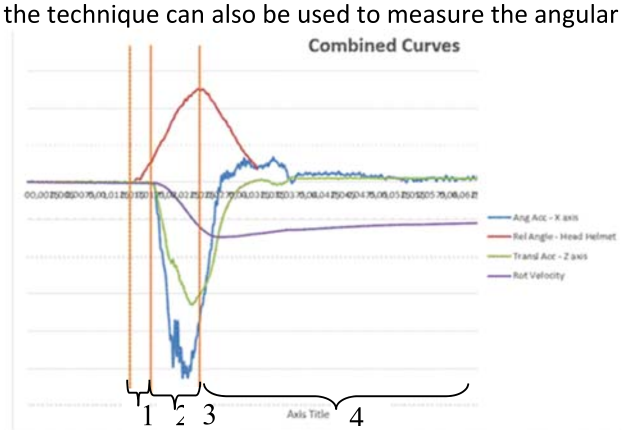

Fig. 8. Example of motion profile pattern stages. Y axis scaled to ease the comparison between curves.

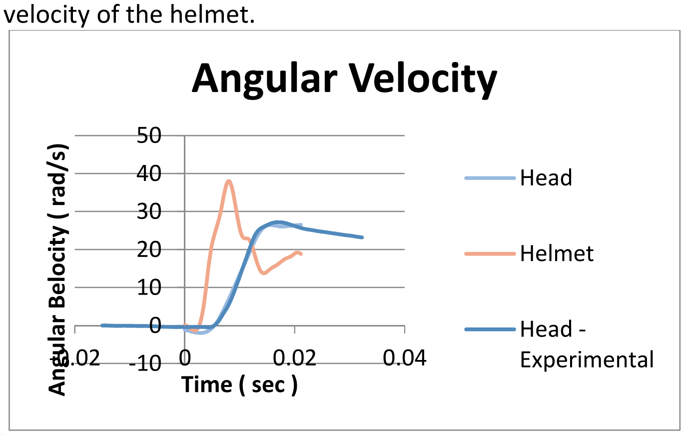

Fig. 9. Example of angular velocity, as measured using motion-tracking and the accelerometers.

IV. DISCUSSION

This research examined the use of 2D motion-tracking to gain an insight into head and helmet kinematics during oblique impact. The technique is accurate and can contribute valuable information towards assessing the kinematics of an impacting helmet on an anvil. A pattern was defined for a helmet impacting an anvil that seems to be repeated throughout all impacts. The existence of a neck on a headform has a negligible, if any, influence on the functionality of the straps as part of the helmet's technology against rotational acceleration. MIPS technology contributed to reducing the relative motion between the head and the helmet and rotational acceleration.

V. REFERENCES

[1[Willinger, R., *et al.*, *International Cycling Safety Conference*, 2014.
[2] Backaitis, *et al.*, *Society of Automotive Engineers*, 1994.
[3] Padgaonkar, A. J., *et al. Appl. Mechanics*, 1975.