MIPS Reduces Headform Kinematics Across a Range of Impact Speeds and Anvil Angles

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I. INTRODUCTION

Cycling-related head impacts from falls and collisions are typically at an oblique angle relative to the impact surface. Reconstructions with follow-up simulations show head impacts occur at 10° to 70° relative to horizontal [1-2], yet free-fall oblique testing of bicycle helmets is often performed only against a 45° anvil [3-5]. A Hybrid III headform is usually used for oblique testing and is typically covered with nylon stockings to reduce the friction between the helmet and the vinyl nitrile skin [5-7]. Tests using a porcine scalp glued to a Hybrid III headform covered with tape showed lower rotational kinematics with the scalp; however, it is not clear how much of the reduction was due to the tape-scalp interface versus the scalp-helmet interface. Here we sought to quantify the effects of MIPS (present, absent), headform condition (bare skin, stocking-covered, human hair) and impact angle (30°, 45°, 60°) on peak headform kinematics during free-fall, oblique bicycle helmet impacts. One impact orientation was tested over four impact speeds. We hypothesized that MIPS would lower the peak rotational headform kinematics compared to no-MIPS and that the reduction with MIPS would be larger than the reduction due to stockings and hair alone for all headform conditions, impact angles and speeds.

II. METHODS

Specialized Echelon helmets (size L) were fit to a 50^{th} percentile Hybrid III headform (4.72 kg) either left bare, covered in two layers of nylon stockings or covered with a human hair wig (Eva & Co. Wigs, Vancouver, BC, Fig. 1b-d). The helmet positioning index was set to 90 mm and the ring-fit system was tightened until slight resistance was met. The chinstrap was adjusted so that 2-3 fingers fit comfortably between the buckle and headform, and low-density foam was then inserted into this space. The headform and helmet were inverted and placed on a U-shaped, freefalling trolley (X- and Y-axes ±1° of horizontal) that fell past a 30°, 45° or 60° anvil covered with 40-grit sandpaper. The headform was oriented to produce a rotation about the anterior-posterior axis (X-axis) at four impact speeds (4.2 m/s, 5.1 m/s, 6.2 m/s, 7.2 m/s). A cantilevered arm holding the headform in place during the freefall released prior to impact and a slack tether attached to the headform prevented secondary impacts. To ensure consistent placement of the headform and helmet, an image of the initial headform position with a no-MIPS helmet was captured and then overlaid on a live image of the MIPS condition at 50% transparency. A helmet with and without MIPS was tested at each impact condition and speed for a total of 72 impacts. Six degree-of-freedom headform kinematics were captured with a 3-2-2-2 accelerometer array (2000 g, TE Connectivity, Schaffhausen, Switzerland; r_x=56 mm, r_y=48 mm, r_z=81 mm) sampled at 50 kHz and high-speed video recorded at 1 kHz (Chronos 1.4, Krontech, Vancouver, BC, Canada). Peak resultant linear acceleration (PLA), angular acceleration (PAA) and angular velocity (PAV) were extracted/computed from the filtered data (CFC 180) and %-reduction (no-MIPS to MIPS condition) was computed for PLA, PAA and PAV. The effects of headform condition and anvil angle on the %-reduction of PLA, PAA and PAV were assessed using a general linear model for each kinematic response variable, with impact speed as a covariate and a post-hoc Tukey's test to evaluate significant differences (α=0.05, Minitab 19, State College, PA, USA). Peak amplitudes were normalized to the no-MIPS, bare-head condition (Fig. 1e).

III. INITIAL FINDINGS

Impact speeds were 4.12 ± 0.06 m/s, 5.10 ± 0.07 m/s, 6.15 ± 0.09 m/s, 7.14 ± 0.09 m/s. Peak rotational kinematics were higher overall at 45° than at the 30° or 60° impact angles. All main effects were significant for the %-reduction of PLA, PAA and PAV, except anvil angle for PAA (p=0.094) and speed for PLA (p=0.890). The %-reduction due to MIPS was significantly larger on PLA and PAV at the 30° anvil condition and significantly lower on PLA, PAA and PAV for the hair condition (Table I).

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Table I: Mean (SD) %-reductions of kinematic variables with MIPS. Anvil angle is defined relative to horizontal. Bold values are significantly different within each kinematic variable.

		PLA		PAA		PAV	
Anvil Angle	30°	**6.91**	**(3.59)**	31.38	(12.36)	**44.56**	**(14.58)**
	45°	7.88	(6.06)	40.27	(9.21)	32.42	(12.16)
	60°	12.05	(8.84)	32.61	(20.49)	29.82	(15.21)
Headform Condition	Bare	12.88	(6.28)	37.55	(7.96)	41.22	(11.96)
	Stocking	10.41	(6.63)	45.12	(12.01)	43.89	(12.15)
	Hair	**3.55**	**(3.13)**	**21.59**	**(13.63)**	**21.68**	**(10.74)**

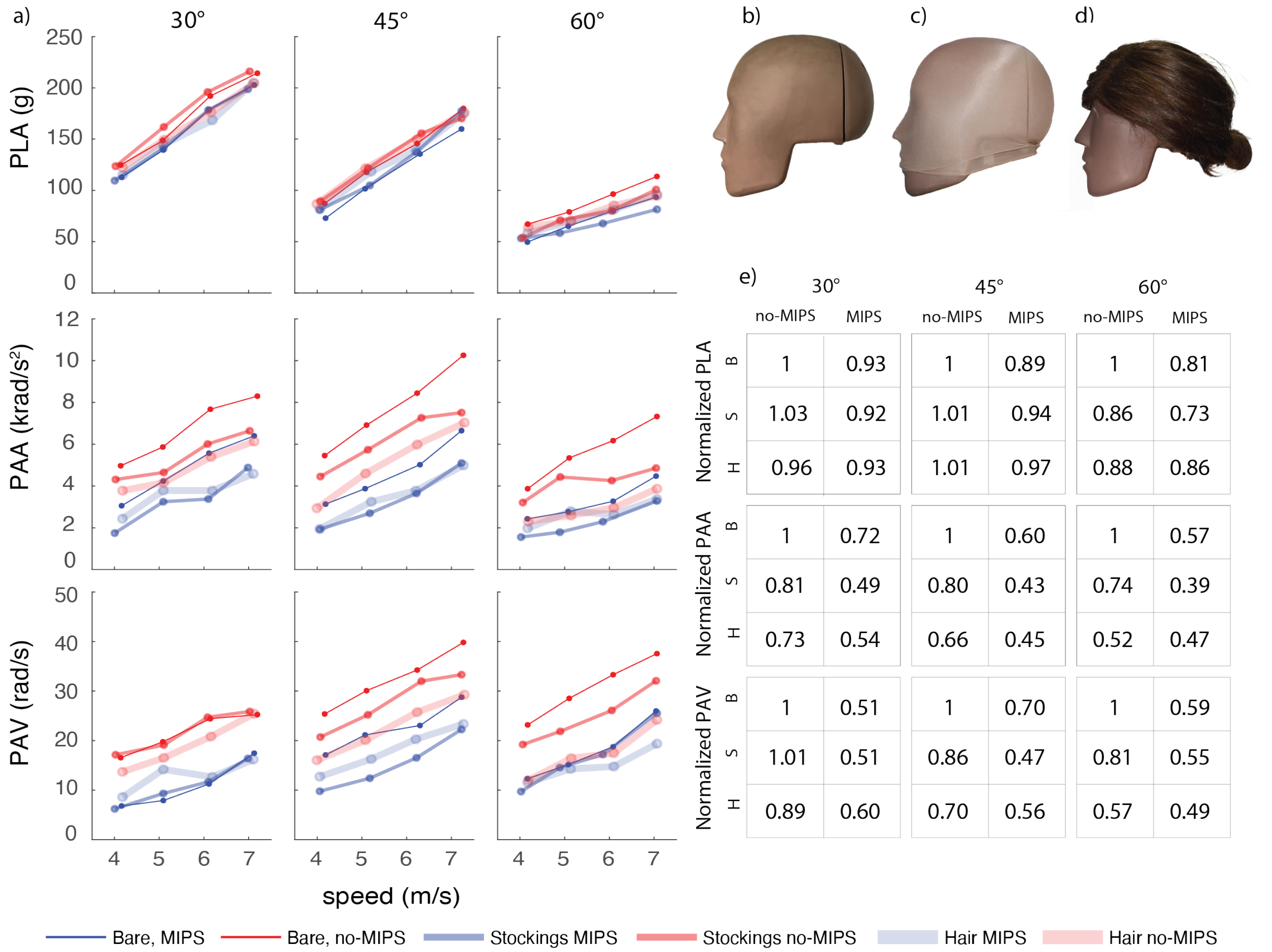

Fig. 1. a) PLA, PAA and PAV for all conditions across the four impact speeds; b) bare, c) stocking, and d) hair headform conditions; and e) average amplitudes of all metrics normalized to the bare, no-MIPS condition. B, bare; S, stocking; H, hair.

IV. DISCUSSION

This study examined the effects of MIPS (present, absent), headform condition (bare, stockings, hair), and impact angle (30°, 45°, 60°) on peak resultant headform kinematics during oblique impacts about the X-axis over four impact speeds. In the no-MIPS condition, hair was more effective than stockings at reducing PAA and PAV relative to the bare condition. MIPS further reduced PAA and PAV in the hair condition, but the %-reduction was less than in the bare and stocking conditions. While MIPS was most effective at reducing PAV at the 30° anvil for impacts that induce rotation about the X-axis, other impact configurations need to be evaluated to assess the overall effectiveness of MIPS. Our study was limited to a single helmet make/model/size and only one impact for each test condition and impact speed. Nevertheless, our data show that MIPS attenuates the head's angular kinematics even when hair is present.

V. REFERENCES

[1] Verschueren, Thesis, 2009. [2] Peng, *Safety Sci*, 2012. [3] Bland, *ABME*, 2019. [4] Bottlang, *ABME*, 2020. [5] Trotta, *J Biomech*, 2018. [6] Bliven, *AAP*, 2019. [7] Bonin, *IRCOBI*, 2020.