The Implications of Surface Friction on Snowsport Helmet Oblique Impact Kinematics

Nicole E-P. Stark[1], Matt Wood[1], Andrew Calis[2], Summer Keim[1], Kristin Dingelstedt[1], Mark Begonia[2], Steve Rowson[1]

[1]Biomedical Engineering and Mechanics, Virginia Tech, USA
[2]Institute for Critical Technology and Applied Science (ICTAS), Virginia Tech, USA

Head injuries account for 15% of snowsport-related injuries, but over 40% of cases the treated at trauma centers [1-3]. Research indicates snowsport helmets reduce head injuries by 21%-45% [4], although optimizing performance through realistic testing could further reduce injuries. Notably, 65%-70% of snowsport TBIs occur against ice or snow, a low friction surfaces [5]. Studies have shown that increased surface friction increases rotational kinematics and impact duration but not linear kinematics [7-9]. Therefore, this study aimed to evaluate how surface friction affects snowsport helmets' oblique impact kinematics.

We measured two helmet models' static coefficient of friction (COF) against high-COF (80-grit sandpaper) and low-COF (steel) surfaces using a custom tribometer [10]. Ten helmet models were impacted using an oblique drop tower with a 45-degree anvil and NOCSAE headform, at three locations (front, side, rear boss), two COF conditions, and a drop speed of 5.0 m/s, informed by real-world data (Figure 1) [5]. Resultant peak linear acceleration (PLA), peak rotational velocity (PRV), and peak rotational acceleration (PRA) were calculated. To account for headform spin direction of the anvil (Figure 3), ARS signals were rotated to align with the resultant rotational velocity vector enabling analysis of a single directional representative ARS signal for each test. Separate mixed linear models ($\alpha<0.05$) compared the effects of location and friction surface, including helmet model, as a random effect on resultant PLA, PRA, and PRV. Post-hoc analysis was conducted with least squares means.

The average COF of helmet shells against 80-grit sandpaper was 0.76±0.03 and 0.27±0.09 against steel. There was a main effect of friction for PLA ($p<0.01$), which decreased from high-COF to low-COF impacts for all locations (Figure 2). PRA ($p<0.01$) and PRV ($p<0.01$) responses varied with friction and impact location (Table 1). To compare severity across impact conditions, we evaluated the resultants without direction, as the symmetrical directional response does not influence injury risk (Figure 2). The low-COF condition decreased the magnitude of PRA and PRV for front impacts and the rear boss had similar severity of rotational kinematics regardless of friction condition. However, PRV and PRA increased at the low-friction condition, indicating that the low-friction side impacts were more severe. There were also variations in headform spin direction between models and impact location. For side impacts, all helmets rolled off the anvil at low COF. However, at high COF, six models bounced off the anvil whereas the other four rolled off (Figure 3). At the rear boss location, only one model changed spin direction after impact. For front impacts, two models changed spin direction based on COF, while eight models showed no change. The variations in PRA and PRV responses may stem from differences in helmet model geometry at impact location or helmet inertia properties

Surface friction affects head impact kinematics, underscoring the need for sport-specific lab testing. Given the study's limited helmet model sample and single speed, future research should expand to more models and speeds. Such research is crucial for improving helmet design to minimize injury and optimize protection for snowsport athletes.

Table 1: Comparison of PRA and PRV response to friction alteration based on impact location.

	PRA [rad/s^2]			PRV [rad/s]		
	p	Difference	Difference 95% CI	p	Difference	Difference 95% CI
Front	0.14	1650	-492, 3792	0.06	7	0, 15
Rear Boss	<0.01	-8965	-11107, -6822	<0.01	-35	-43, -27
Side	<0.01	6067	3924, 8209	<0.01	23	15, 31

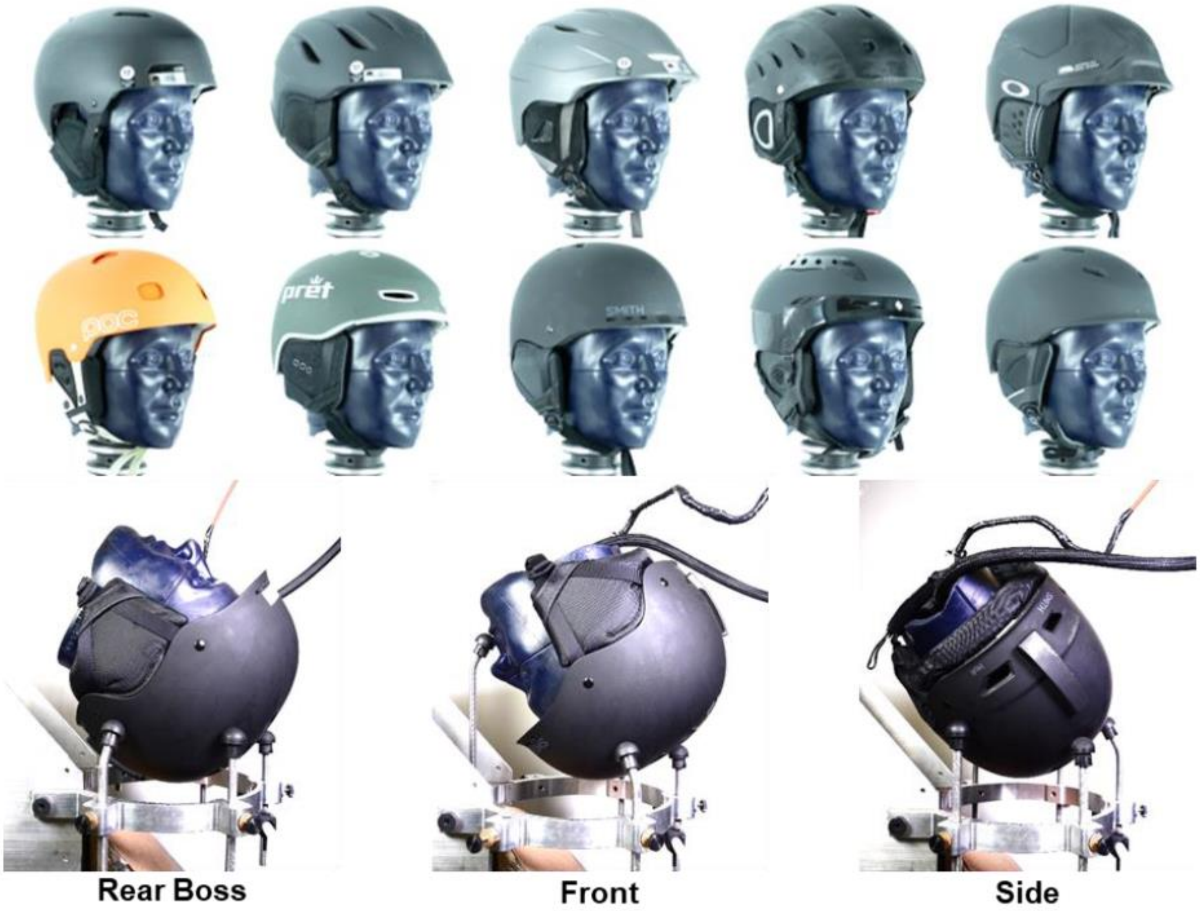

Figure 1: Ten helmet models tested and the three impact locations.

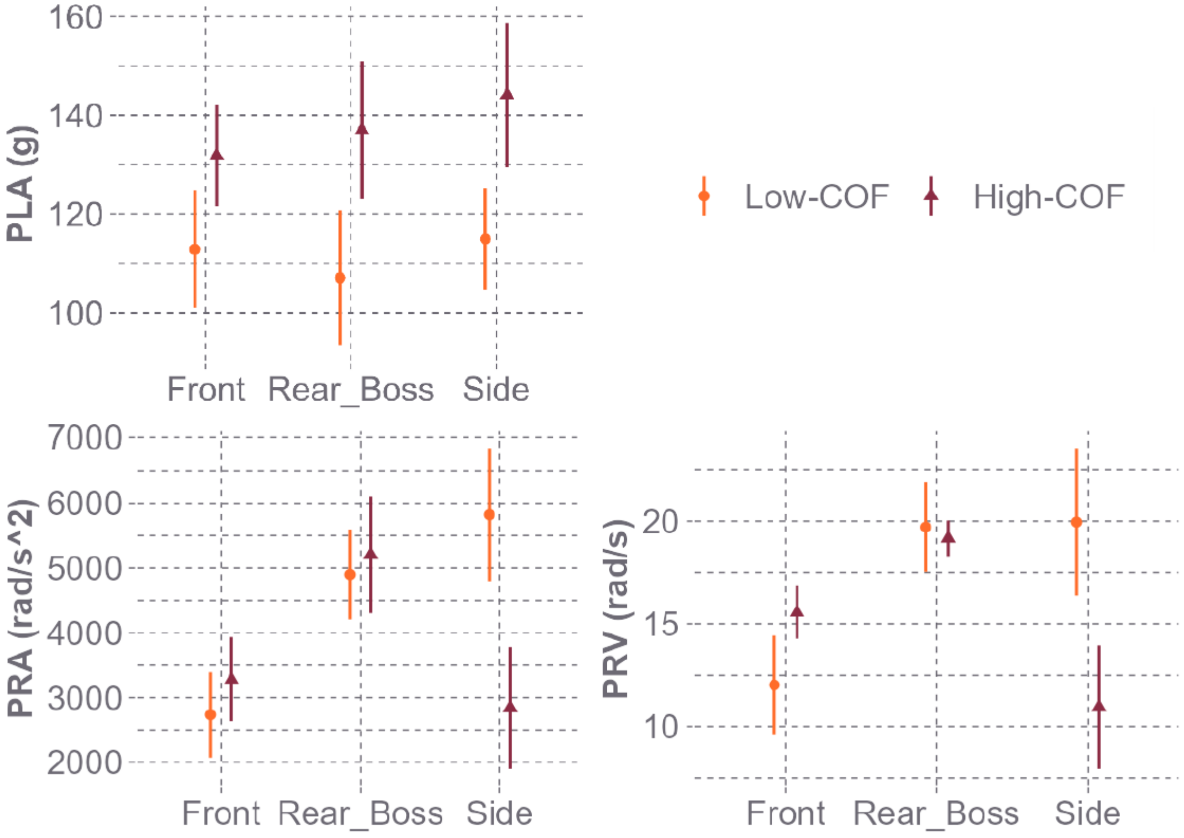

Figure 2: Magnitude comparison of peak resultant linear acceleration (LA), rotational acceleration (RA), and rotation velocity (RV) for high friction (High-COF), 80-grit sandpaper, and low friction (Low-COF), steel.

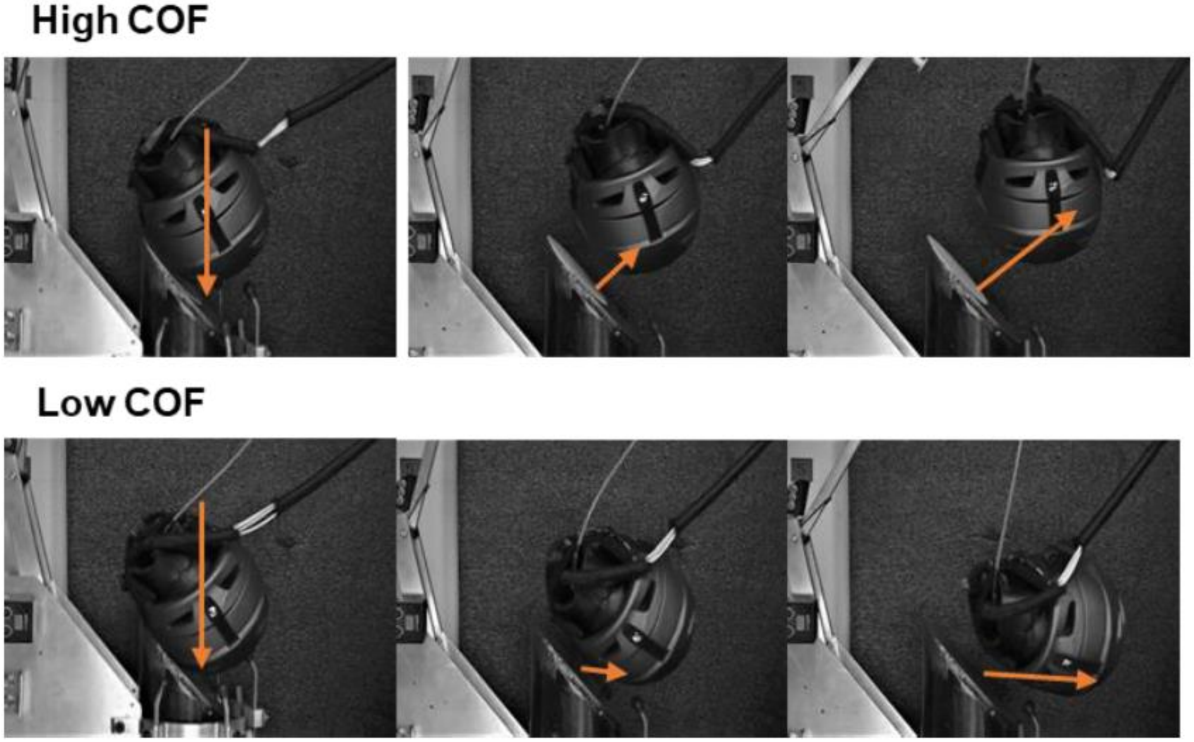

Figure 3: Representative impact sequence for the high COF surface (80-grit sandpaper), where the helmet bounces off the anvil spinning clockwise, and the low-COF surface (steel), where the helmet rolls off the anvil spinning counter-clockwise.

References:

[1] U.S. Consumer Product Safety Commission. (1999);
[2] Wasden et al. (2009) Trauma Inj. Infect. Crit. Care 67(1022–1026);
[3] Weber et al. (2015) Eur. J. Trauma Emerg. Surg.;
[4] Russell et al. (2010), CMAJ 182(4 333-340);
[5] Bailly et al. (2023), JSAMS Plus 2(100028);
[6] Petersen et al. (2020), J Sports Engineering and Technology, 234(4);
[7] Kent et al. (2020), ABME, 32(3);
[8] Bonugli et al. (2017), SAE Technical Paper;
[9] Finan et al. (2008), Traff Inj. Prev. 9(5 483-488);
[10] Stark et al. (2023), IRCOBI;