Headform Friction Coefficients and Implication on Oblique Helmet Testing
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Introduction
To evaluate helmet designs, various standards and independent test methods use different helmet-testing headforms, each with unique inertial and friction properties. Questions about the influence of the frictional interfaces between the headform and helmet linear on impact response have arisen due to the increased focus on oblique impact testing and mitigating rotational response. During oblique impacts, peak rotational acceleration (PRA) and peak rotational velocity (PRV) have been found to be sensitive to adjusting friction for a singular headform, but the overall effect was not quantified. Furthermore, only one study has compared headforms with different moments of inertia (MOI) and frictional properties, finding differences in PRV and PRA. However, the effect of friction alone was not quantified. Therefore, this study’s objective was to quantify the influence of headform coefficient of friction (COF) on oblique impact response.

Methodology
Oblique impact testing was completed using guided drop tests of a helmeted headform onto a 45-degree anvil with 80-grit sandpaper. Tests were conducted on each headform at two velocities (4.8 and 7.3 m/s), two locations (y-axis and x-axis rotation), and two friction configurations (bare and skull-cap). Using a specially designed tribometer, the NOCSAE and Hybrid-III (bare and skull-cap) static COF were measured against the helmet’s lining material. Each headform was instrumented, at the center of gravity, with a six-degree-of-freedom sensor package consisting of three accelerometers and a tri-axis angular rate sensor (ARS). Data were collected at a sampling rate of 20 kHz and filtered using a 4-pole Butterworth low-pass filter with cutoff frequencies of 1650 Hz (CFC 1000) for accelerometer signals and 289 Hz (CFC 175) for ARS signals. Resultant peak linear acceleration (PLA), PRA, and PRV were calculated for each test. ANCOVAs were conducted to determine the effect of friction on the oblique impact response of the headforms at each velocity while covarying for location and mass for PLA or axis MOI for PRV and PRA. The sum of squares were used to determine the percent of variance in kinematic response that friction coefficient accounted for.

Results and Conclusions
Against the helmet lining material, the static COF were 1.00±0.02 NOCSAE, 0.91±0.01 Hybrid-III, 0.30±0.02 NOCSAE skull-cap, and 0.29±0.02 Hybrid-III skull-cap. Friction accounted for the majority of difference at high-velocity (7.3 m/s) impacts across all measures; PLA (P<0.001, 36%), PRA (P<0.001, 53%), and PRV (P<0.001, 44%). However, at the low-velocity impacts (4.8 m/s), friction only had a statically significant effect on PRV (P<0.001, 22%). Therefore, our finds agree with previous literature that the effect of friction is also based on tangential velocities. Although there was a statically significant difference in PRV at both velocities, the measures only differed by 1-3 rad/s. PLA increased by 9-35 g for higher friction conditions, and PRA increased by 160-1600 rad/s². These results indicate that friction influences oblique impact testing at high velocities, predominantly for PLA and PRA. Furthermore, because of the influence of friction on oblique impact response, headforms should have human-like friction.