The Protective Performance of Industrial Safety Helmets under Falls and Trips in the Workplace

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I. INTRODUCTION

Traumatic brain injury (TBI) is a common injury in the workplace. Trips and falls are the leading causes of TBI in workplace [1]. However, current industrial safety helmets are not designed for protecting the head under these impact conditions. Instead, they are designed to pass the regulatory standards which test head protection against falling heavy and sharp objects. In our recent study, we used validated human multi-body models to simulate over a thousand falls and trips and determine several representative head impact conditions for these scenarios, including head impact location, speed and angle (the angle between the impact velocity and the ground) [2]. In this study, we tested an industrial helmet under these impact conditions and assessed the head injury severity. Our study provides an initial understanding of the safety helmet's protective performance in trips and falls scenarios.

II. METHODS

The parameters of the four representative test conditions are summarized in Table 1. The impact location was defined using the elevation angle and azimuth angle [2]. We used a 50th Hybrid III dummy headform to test the JSP EVO3 linesman helmet, a type of helmets that is often used in industrial settings (Fig. 1). We used an angle-adjustable flat anvil to achieve the impact angle. We used two different materials, 80-grit abrasive paper (P80) and the roofing shingle, to cover the anvil surface (Fig. 1). P80 represents high, yet realistic, friction while roofing shingle represents concrete surface [3]. Each test was repeated three times with three samples.

TABLE 1 The parameters of the impact test condition [2].

Impact conditions	**Trip 1**	**Trip 2**	**Fall 1**	**Fall 2**
Impact speed (m/s)	2.7	3.9	3.8	5.5
Impact angle (degree)	45	75	45	75
Elevation angle (degree)	40.3	36.2	43.8	38.8
Azimuth angle (degree)	-30.2	-23.7	-2.9	16.5

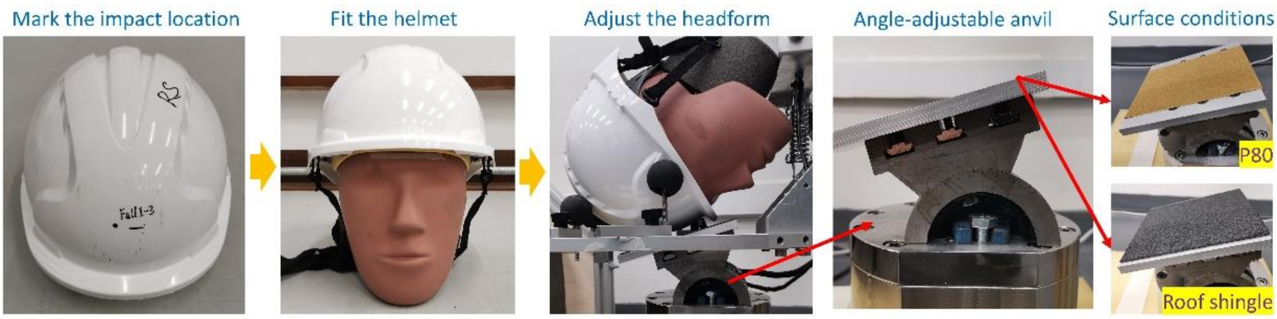

Fig. 1. Helmet-headform fitting and impact test setup.

We used a nine-accelerometer package (NAP) installed inside the headform to measure linear and rotational accelerations of the headform. The accelerations were sampled at 50 kHz and filtered using a fourth-order Butterworth filter at a cut-off frequency of 1 kHz. The rotational velocities were obtained by integrating the rotational accelerations vs. time [4]. We used three injury metrics to assess the helmet performance: peak translational acceleration (PTA), peak rotational acceleration (PRA) and peak rotational velocity (PRV).

III. INITIAL FINDINGS

Fig. 2 shows the snapshots from high-speed videos of the four impact conditions. The helmet started to contact the anvil surface at 1 ms and finished around 26 ms. At 52 ms, the helmet had detached the anvil, when the headform rotation can be seen clearly. In each impact condition, the helmet had more rotation

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when impacted on the P80-covered anvil than the roof shingle-covered anvil. All impact conditions produced anti-clockwise headform rotation, except from the Fall 1 condition with roof shingle where the headform underwent a clockwise rotation. The Trip 2 and Fall 2 impact conditions, where the anvil was 75°, produced large rebounds of the headform in the vertical direction.

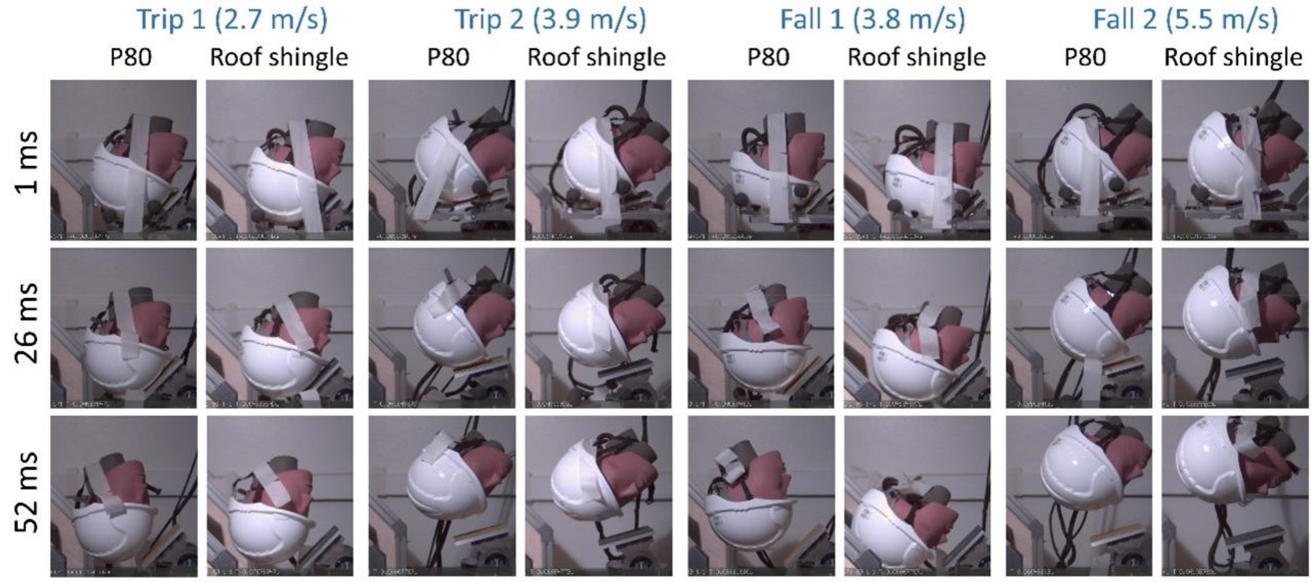

Fig. 2. Snapshots from the high-speed videos of the helmeted headforms under the four impact conditions.

TABLE 2 The mean values of the three injury metrics under different impact conditions.

Injury metrics	Surface condition	Trip 1	Trip 2	Fall 1	Fall 2
PTA (g)	P80	43±1.0	159±5.1	69±1.0	377±20.4
	Roof shingle	38±1.0	166±3.5	61±8.0	377±5.9
PRA (krad/s^2)	P80	**2.09±0.1**	4.94±1.4	**3.19±0.2**	5.26±0.8
	Roof shingle	**1.44±0.1**	4.28±0.5	**1.67±0.3**	5.86±0.6
PRV (rad/s)	P80	**16.3±0.3**	**13.9±3.7**	**16.6±0.8**	9.6±1.4
	Roof shingle	**8.4±0.6**	**9.7±1.3**	**6.7±1.3**	9.3± 1.8

As shown in Table 2, the difference in the PTA for P80 and Roof Shingle surfaces was small (max 11.6%). For the two 45° anvil impacts (Trip 1 and Fall 1), P80 surface compared with roof shingle produced higher PRA (max difference = 48%) and PRV (max difference = 60%). For the 75° anvil impacts (Trip 2 and Fall 2), only Trip 2 produced a large difference in PRV (30%).

IV. DISCUSSION

We tested an industrial helmet under oblique impacts representing trips and falls. Fall 2 produced PTAs (377 g) significantly larger than 250 g, which is the threshold of 40% risk of skull fracture [5]. Trip 2 also produced relatively large values of PTAs (159 g and 166 g), considering the low impact speed. The PRAs produced by Trip 2 and Fall 2 are over the threshold of 25% probability of mild TBI (4.6 krad/s^2) [6]. The surface condition had a significant effect on the injury metrics based on head rotation (PRA and PRV). One limitation of this study is using the HIII headform, which has fidelity shortcomings compared with the human head [7]. This study provides an initial understanding of the performance of industrial helmets under impact conditions that are the main cause of TBI in industrial settings. This work is a step towards improving industrial helmet standards.

V. REFERENCES

[1] Brolin, K., et al., Saf. Sci, 2021
[2] Yu, X., et al., Ann. Biomed. Essssng, 2023.
[3] Bonugli, E., et al., SAE Technical Paper, 2017.
[4] Yu, X., et al., Ann. Biomed. Eng, 2022.
[5] Mertz, H.J., et al., SAE Transactions, 1997.
[6] Zhang, L., et al.,. J. Biomech. Eng., 2004.
[7] Yu, X., et al., Front. Bioeng. Biotechnol, 2022.