Comparing Kinematics of Vertical Drop Towers and Free-Falling Surrogates in Frontal Falls from Height

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I. INTRODUCTION

Fall-related traumatic brain injury (TBI) presents a significant risk to military personnel, as evidenced by the approximately 20% of reported TBIs in the military being attributed to falls [1-2]. Consequently, assessing headgear for falls is important. It is an open question whether the simple drop towers in use today accurately simulate real-world falls. Drop towers are constrained to a single degree-of-freedom, and the impact mass of a drop tower assembly typically only includes the mass of the head and neck rather than the mass of a full body [3]. The objectives of this work are to study the kinematic differences that likely exist between a drop tower and a falling person due to these constraints and to identify if increasing drop carriage mass to simulate body mass can result in a drop tower accurately simulating a fall of a human.

II. METHODS

A guided drop tower equipped with a Hybrid III head/neck and adjustable weight drop carriage, Fig. 1(a), along with a full-body Hybrid III 50th percentile male surrogate, to represent a falling person Fig. 1(b), were subjected to headfirst impacts at four angles, between 30° and 75°, and four impact velocities, between 1.50 m/s and 3.00 m/s. The impacts were conducted onto a rigid impact surface and kinematic measures of head linear acceleration (Peak g), angular acceleration (Peak α), and angular velocity (Peak ω) were measured. To ensure repeatable impact velocities across all test angles the release height was set via a measured height between the impact surface and a target placed on the head that aligned with the head center of gravity (COG). For the free-falling surrogate orientation was verified before release by aligning the position target on the head with a laser line set at the required release height along with aligning positional targets placed on each shoulder with a secondary laser line. The fall angle was defined as the angle of the neckline as measured just prior to release by way of an angle finder placed along the neck Fig 2. Head position and impact angle were verified immediately before surface impact, in both scenarios, via high speed footage in which the angle between the impact surface and the neck axis were measured.

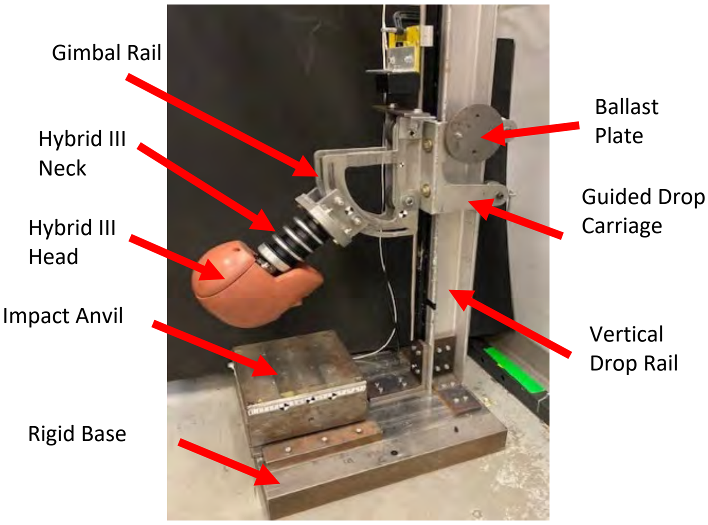

Fig. 1(a) Vertical drop tower system fitted with Hybrid III head/neck and custom drop carriage.

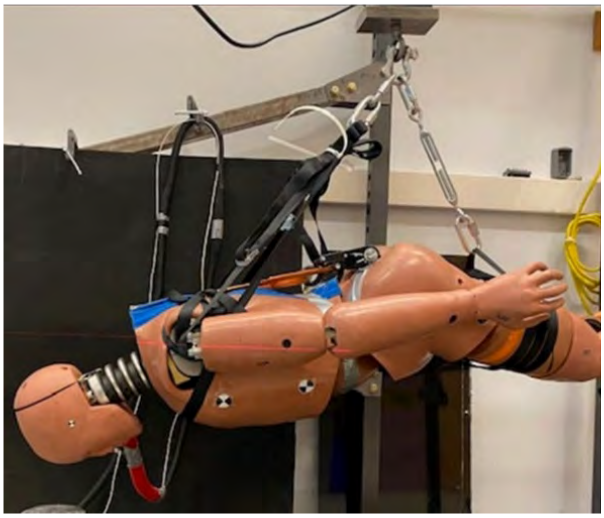

Fig. 1(b). 50th Percentile HIII surrogate model used in free fall impacts.

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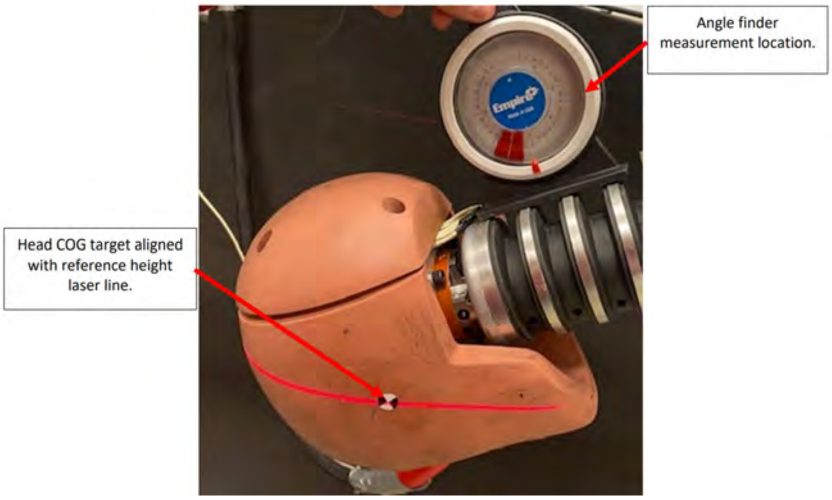

Fig 2: Measurement of fall angle just prior to release via an angle finder placed along the neckline with the head COG target aligned with the fall height reference line to achieve target impact velocity.

III. INITIAL FINDINGS

Statistical comparisons, via one-way Welch ANOVA, with a significance of $p<0.05$, and Games-Howell post-hoc analysis, between each drop tower mass and the falling surrogate were conducted for each impact angle. i.e. the mean kinematics for each 30° configuration were only compared against other 30° configurations and not the mean kinematics of other impact angles. Results of the impact study, Table I, show that the drop tower produces Peak g and Peak α that are not statistically different from a falling surrogate across the test configurations However, Peak ω measures were found to differ between the two impact scenarios for select configurations. Additionally, for the 60° and 75° configurations, where no significant differences in Peak ω were observed, it was found that the angular velocity components differed in direction and time instance between a guided drop tower and a free-falling surrogate. The drop tower showed a delayed peak in the opposite direction relative to the angular velocity response of the falling surrogate shown in Fig. 3 for the 60° 2.50 m/s test conditions. The causes of the delayed opposite peaks for the non-statistically different configurations were investigated through high-speed video. Target tracking of head motion during and after initial impact, Fig. 4(a), shows that the surrogate model experiences head/neck flexion while also translating along the impact surface. Conversely, the drop tower, although initially experiencing flexion, rebounds from the impact surface after initial impact before experiencing extension of the head/neck due to the constraints of the drop tower. The delayed opposite rotation observed in the angular velocity components can be attributed to this extension of the head/neck. Differences in head motion were observed for all carriage masses at 60° and 75°, indicating that varying carriage mass does not alter head motion after initial impact. Motion differences were not observed in 30° impacts, Fig. 4(b), as the head of the full surrogate purely rotated in the same manner as the drop tower.

TABLE I
SUMMARY OF DIFFERENCES IN KINEMATIC MEASURES BETWEEN A FULL-SURROGATE AND WEIGHTED DROP TOWER

		30°				45°				60°				75°			
Full-Surrogate	Carriage Weight	11.75 kg	14.22 kg	16.70 kg	19.17 kg	11.75 kg	14.22 kg	16.70 kg	19.17 kg	11.75 kg	14.22 kg	16.70 kg	19.17 kg	11.75 kg	14.22 kg	16.70 kg	19.17 kg
	Peak g																
	Peak α																
	Peak ω	X				X	X	X	X			X	X			X	X

Blue indicates that the drop tower underestimates peak kinematics, red indicates that the drop tower overestimates peak kinematics, and X through the cell denotes statistically significant difference.

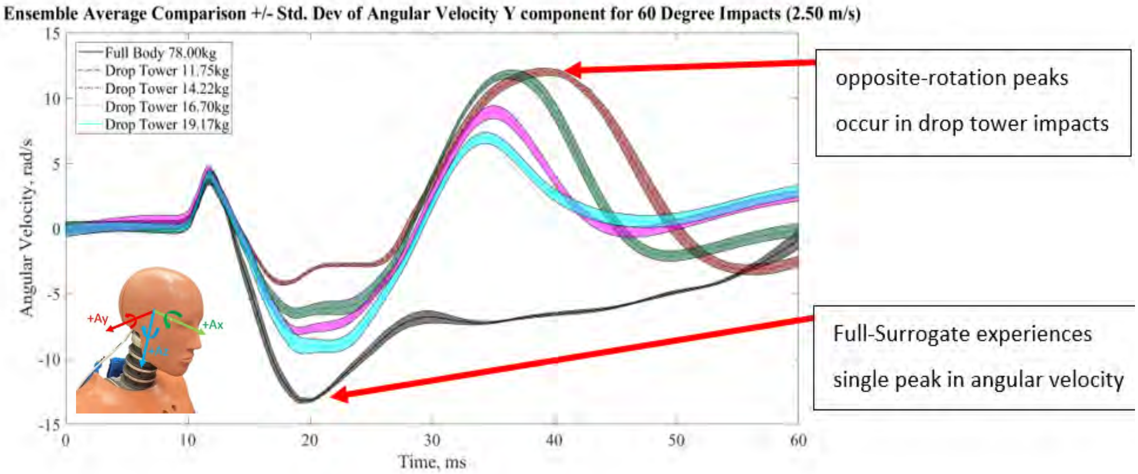

Fig. 3. Ensemble time trace of Y component angular velocity, shown for 2.50 m/s, 60° impact. Angular velocity peak for drop tower is delayed and in opposite direction of surrogate (positive indicates extension negative indicates flexion).

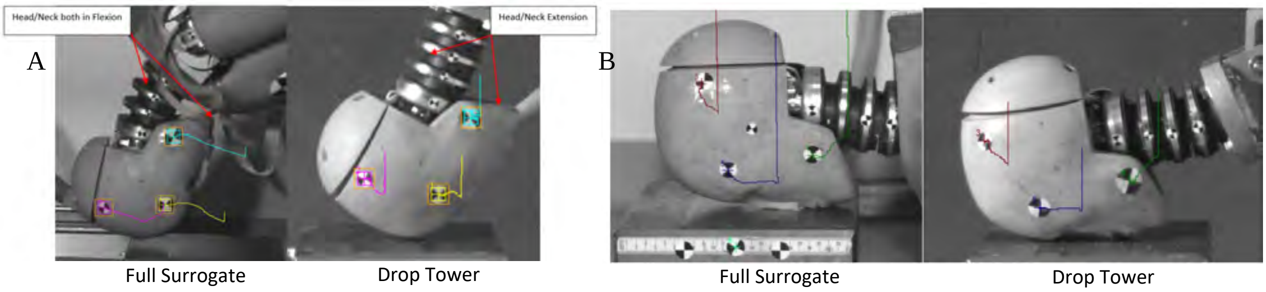

Fig. 4 (a) 75° impact depicting head/neck flexion in falling surrogate vs head/neck extension in drop tower. (b) 30° impact depicting similar head/neck motions between falling surrogate and drop tower.

IV. DISCUSSION

The findings of this work indicate that guided drop towers, in their current form, exhibit differences in their angular velocity components when compared to those of an actual fall, particularly when comparing in steep angle falls. This work indicates that guided drop towers do not create impact mechanics of the head representative of a falling human body. The fact that angular velocity differs between drop towers and falling dummies is an issue that should be addressed because angular velocity is a key measure often used in estimating the risk of TBI and in several risk models and risk functionals based on kinematics [4]. Future work will focus on designing a drop tower that modifies neck constraint to achieve a more accurate approximation to a falling human.

V. REFERENCES

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