Comparison of the Hybrid III and Human Volunteer in Low-Severity Lateral Head Impacts

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I. INTRODUCTION

Anthropomorphic testing devices (ATDs) have historically been used to predict injury and evaluate safety measures in automotive injury research. The 50th percentile male Hybrid III ATD was developed for frontal automotive crashes with the head and neck designed for biofidelity in the sagittal plane [1-2]. However, the Hybrid III ATD is also frequently used to evaluate injury risk in sports, particularly in head impact reconstruction and helmet testing [3-5]. There has been some debate regarding the biofidelity of the Hybrid III ATD as a tool for omni-directional helmet loading [6], and since the Hybrid III neck is a passive compliant element, it is not clear how closely it represents a living human that can actively control the level of neck muscle tension. The goal of this study was to determine the effect of varying levels of active neck muscle tension in human volunteers in response to a direct head impact, and to assess the biofidelity of the Hybrid III head-neck by comparing kinematics from the ATD to human volunteers under three neck muscle activation conditions.

II. METHODS

A volunteer study was completed using 20 healthy, male subjects (age = 22.8 ± 3.0 years, height = 177.4 ± 3.5 cm, mass = 78.2 ± 9.5 kg), each exposed to three non-injurious head impacts. All methods and tests performed in this study were approved by the UVA Institutional Review Board. Each volunteer was subjected to a comprehensive battery of clinical assessments prior to testing, and the same assessments were performed one-day and one-week post-impact. The assessments included symptom checklists, neuropsychological and balance tests, and multi-modal magnetic resonance imaging.

Three non-injurious head impacts were delivered to each volunteer using a pendulum system with a padded 3.7 kg spherical impactor. The impactor was positioned such that it struck the volunteers on the side of the head at 2 m/s, three inches above the right ear. The volunteers wore custom-fit mouthpieces with a six degree-of-freedom sensor package to measure head kinematics. Each volunteer was tested at three levels of neck muscle activation: passive, maximum co-contraction, and maximum unilateral contraction against a head strap. Surface electromyography of the sternocleidomastoid and upper trapezius muscles were recorded to quantify the activation level prior to each impact. The Hybrid III ATD was tested in the same manner as the passive volunteers, and the impact was repeated three times.

All mouthpiece sensor data were transformed to the volunteer head centre of mass determined via the neuroimaging data. Angular accelerations were calculated using a central difference method from the angular velocity kinematics. Durations of angular velocity were determined using the time between the signal crossing 15% of the maximum before and after the peak. Head kinematics corridors were developed using a mean response +/- one standard deviation at each time point. Statistical significance of head kinematic peaks and durations was determined using a two-tailed, t-test for equal means with unequal variance ($\alpha = 0.05$).

III. INITIAL FINDINGS

All post-test clinical assessments showed no deviations from baseline, and all subjects were asymptomatic at both one-day and one-week post impact. Within the volunteer data, there was a 49% decrease in the x-angular velocity duration between the passive and maximum unilateral conditions (Fig. 1). Additionally, there was an 11% decrease in volunteer peak linear head acceleration in unilateral activation relative to the passive condition. The Hybrid III peak head linear resultant acceleration fell within the passive and unilateral volunteer

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conditions, simulating the physiological data (Fig. 1), and the average ATD peak resultant linear acceleration (11.0 ± 0.5 g) was between the co-contracted and unilateral peaks (Table I). The average peak angular velocity for the Hybrid III, -6.5 ± 0.1 rad/s, was approximately the same as the co-contracted peak x-angular velocity, -6.6 ± 0. 79 rad/s. In addition to the reduction in x-angular velocity duration with increased muscle activation, there was an additional 30% decrease in duration between the unilateral condition and the Hybrid III response. Finally, the increased x-angular acceleration of the Hybrid III, -874.9 rad/s^2, was significantly higher from all of the volunteer muscle conditions (Table I).

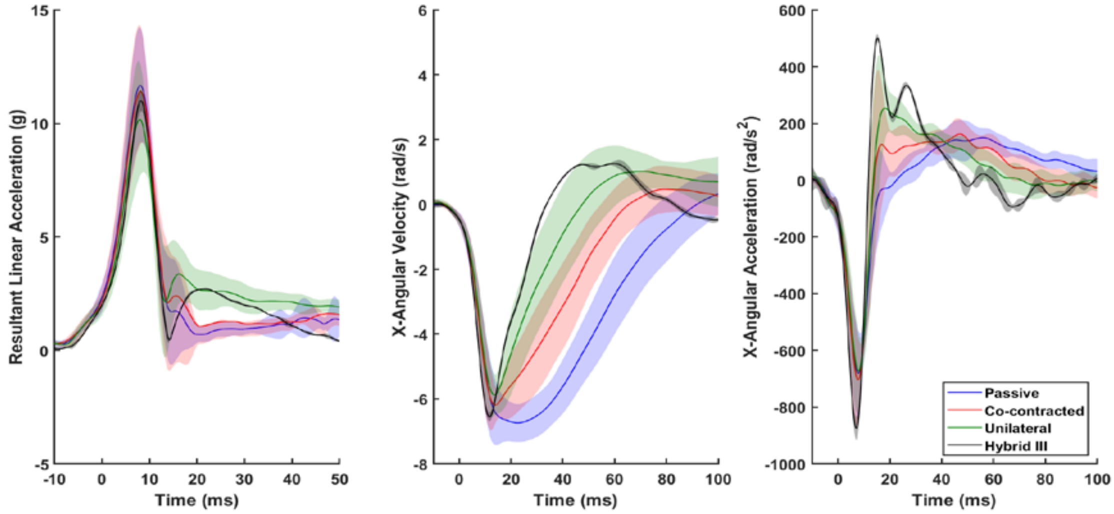

Fig. 1. The mean (± 1 SD) head resultant linear acceleration, x-angular velocity, and x-angular acceleration for each muscle activation condition and the Hybrid III response. All kinematic data in SAE coordinates.

TABLE I
THE PEAK HEAD LINEAR RESULTANT ACCELERATION, X-ANGULAR VELOCITY, AND X-ANGULAR ACCELERATIONS FOR EACH MUSCLE ACTIVATION CONDITION FOR THE HUMAN VOLUNTEERS AND THE HYBRID III

	a_{res} (g)	ω_x (rad/s)	α_x (rad^2/s)
Passive	12.1 ± 1.8	-6.9 ± 0.6	-714.7 ± 111.9
Co-contracted	12.1 ± 1.5	-6.6 ± 0.7	-767.4 ± 96.8
Unilateral	10.7 ± 1.7	-6.2 ± 0.6	-733.4 ± 83.3
Hybrid III	11.0 ± 0.5 *†	-6.5 ± 0.1 *§	-874.9 ± 40.5 *†§

Significantly different ($p < 0.05$) compared to volunteer passive (*), co-contracted (†), and unilateral (§).

IV. DISCUSSION

The goal of this study was to determine volunteer head response to various states of neck muscle activation, and to compare these results to the Hybrid III during a non-injurious lateral head impact. While the Hybrid III had similar peak resultant linear acceleration and peak x-angular velocity to the volunteers for unilateral contraction and co-contraction, respectively, the x-angular acceleration was significantly higher than any of the muscle activation conditions. In addition, the overall movement and rotation of the Hybrid III head was smaller than the stiffest volunteer condition of maximum unilateral contraction. These conclusions are limited to low-severity lateral impacts.

V. REFERENCES

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