Head and T1 angle analysis of small female PMHS, mid-size male PMHS and mid-size male NBDL volunteers

Corina Espelien, Mary Gallaher, John Paul Donlon, Jason Forman

I. INTRODUCTION

The head is one of the most commonly injured regions of the body in motor vehicle collisions [1]. To better predict head motion in an impact-like scenario, quantifying the neck response in a simplified laboratory setting is critical to understand the underlying biomechanics of head-neck system. Testing from Naval Biodynamics Laboratory (NBDL) provides data for the neck response of mid-size male volunteers, but there are not comparable datasets for occupants outside of this demographic. Therefore, examining different anthropometries (e.g. small female and mid-size male) and surrogate types (e.g. volunteers and post-mortem human subjects (PMHS)) to supplement original NBDL data can use useful for injury prediction tools, evidence for the potential effects of muscle tensing, and context for observed field injury trends.

II. METHODS

Frontal impact sled tests were conducted on six small female and three mid-size male PMHS using a reverse acceleration sled system. PMHS testing procedures followed the ethical guidelines established by the National Highway Traffic Safety Administration (NHTSA) and were reviewed and approved by a biological protocol committee at the Center for Applied Biomechanics and University of Virginia (UVA) Institutional Review Board–Human Surrogate Use Committee. Each PMHS was subjected to sequential 3 g (20 km/h) and 8 g (43 km/h) sled pulses. The testing environment (Fig. 1) was designed to replicate NBDL testing [2] (details in [3]). From the PMHS data, sagittal head and T1 rotation were determined from motion tracking of bone-mounted marker arrays. To compare to original NBDL data, NBDL cases listed in Espelien *et al.* [3] were accessed from the NHTSA Biomechanics Database (NHTSA-BD) [4] and the T1 angle was corrected per the method described in Thunnissen [5] for surface-mounted spine instrumentation. Data are presented in the SAE coordinate system (sagittal positive angles as rearward rotation and negative angles as forward rotation) with respect to the sled coordinate system and the angles reported as change in angle from the start of the test.

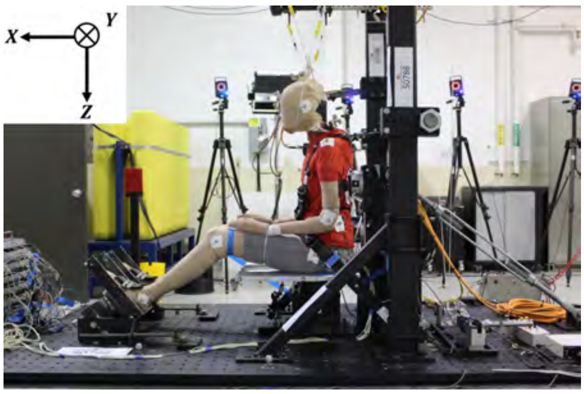

Fig. 1. UVA testing environment replicating NBDL conditions. A representative small female PMHS shown.

III. INITIAL FINDINGS

The head-T1 angle plots for data from t=0 to t=250 ms for the UVA PMHS (NHTSA-BD REF#UVAS0785-UVAS0802) and NBDL male volunteers are shown in Fig. 2. The PMHS exhibited an initial phase of head forward rotation with minimal T1 rotation (<10°) until about 40° of head forward rotation. After 40° of head forward rotation, the head and T1 angle exhibit an approximately linear relationship; averaged across all subjects, the

C. Espelien (e-mail: cme2kd@virgina.edu; tel: +1-434-297-8050) is a PhD candidate, M. Gallaher is an undergraduate researcher, J. P. Donlon is a senior research specialist, and J. Forman is a Principal Scientist at the Center for Applied Biomechanics at University of Virginia, USA.

median gradient was 1.3° head forward rotation per 1° T1 forward rotation for both the 3 g and 8 g tests. The small female and mid-size male PMHS responses were similar. For the 8 g NBDL data, the initial motion exhibited minimal head rotation while T1 rotated, followed by head forward rotation with minimal T1 rotation until rebound (head and T1 angle become more positive). The maximum head and T1 forward rotations (on average) were less for NBDL volunteers than the PMHS for both the 3 g and 8 g pulses. Comparing head forward rotation at the two impact severities presented, the reduction in maximum head forward rotation from 8 g to 3 g (reported as mean±std) were 18±7%, 14±3% and 38±15% for the small female PMHS, mid-size male PMHS and mid-size NBDL male volunteers, respectively.

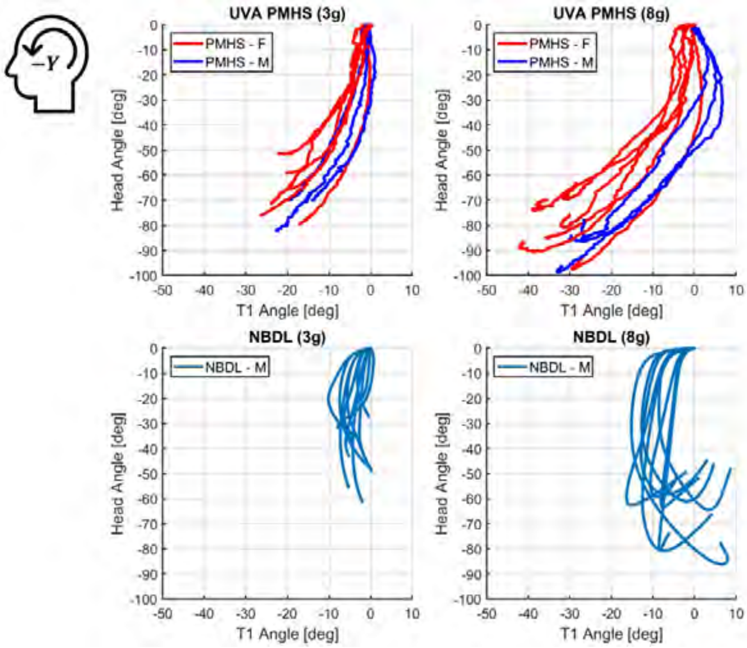

Fig. 2. Head angle vs. T1 angle for UVA PMHS (top, with females in red and males in blue) and NBDL volunteers (bottom, males in blue) for two test pulses (3 g, left, and 8 g, right).

IV. DISCUSSION

The head-T1 angle curves for PMHS and NBDL volunteers exhibit different characteristics, especially in the 8 g case (Fig. 1, right). The initial PMHS motion (for both small female and mid-size male) is head forward rotation, while the NBDL male volunteers data initially exhibit minimal head forward rotation; the delay in head forward rotation for NBDL volunteers data may be due to many variables, including differences in extensor muscle contraction, initial positioning of the head and torso, initial response of the torso (represented by T1), and passive stiffnesses or flexibilities of the head-neck system. The curves presented use the T1 angle, which represents the motion at the base of the neck. These curves differ from neck-link angle [5], which describes the rotation of the segment from T1 to approximate location of the occipital condyles (OC). The neck-link angle includes OC motion due to neck bending; therefore, neck-link angles [5] are typically larger than the isolated T1 angles in Fig. 2. Lastly, volunteers exhibited nearly two-fold reduction in maximum head forward rotation compared to PMHS (female or male) from 8 g to 3 g tests, which may be indicative of the stiffening effect of muscle tensing in the volunteers. However, as the head rotation presented is a global kinematic, it is not directly indicative of solely neck muscle tensing. Rather, the difference at two impact severities between volunteers and PMHS in matched conditions could be influenced by differences throughout the body and could be better understood in future analyses of relative kinematics (e.g. head kinematics in a T1 coordinate system).

V. ACKNOWLEDGEMENTS

US Department of Transportation National Highway Traffic Safety Administration provided both technical and financial support via Contract No. 693JJ921F000180. The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Department of Transportation or the National Highway Traffic Safety Administration. The United States Government assumes no liability for its contents or use thereof.

VI. REFERENCES

[1] Forman, J., *et al.*, *TIP,* 2019.
[2] Ewing, C., *et al.*, *SAE,* 1968.
[3] Espelien, C., *et al.*, *ESV,* 2023.
[4] US DOT, NHTSA Biomech. Database.
[5] Thunnissen, J., *et al., SAE,* 1995.