Neck Influence on Head Kinematics and Implications for Helmet Evaluation and Brain Injury

Mark Begonia, Frank A. Pintar, Narayan Yoganandan

I. INTRODUCTION

Diffuse brain injury, including concussion, is widely known to have a stronger correlation with the angular motion of the head than with the linear motion [1-2]. However, some helmet evaluations do not incorporate a mechanical neck surrogate for inducing angular head motion. In addition, many studies on mild traumatic brain injury (mTBI) and helmet performance have only utilised the Hybrid III (H3) neck [3-8] for tests in multiple directions, despite the availability of necks from side-impact dummies such as the EuroSID-2 (ES-2). Another issue with helmet assessments is determining the appropriate neck for oblique loads, as available options were designed originally for frontal or side impacts. The role of the neck is important given that helmet performance and potential for brain injury depend on head kinematics, which are in turn affected by the neck response. The objective of this study is to investigate the influence of the neck on head kinematics under oblique loads.

II. METHODS

Inertial loading tests were conducted on a rigid arm pendulum designed for dummy neck calibration and inducing angular loads [8]. A medium National Operating Committee on Standards for Athletic Equipment (NOCSAE) head, which is used for evaluating the performance of various sports helmets, was instrumented with a nine-accelerometer package at the centre-of-gravity (CG), with signals filtered under SAE J211 specifications. The NOCSAE head was attached to the H3 neck using a commercially available adapter and to the ES-2 neck using a custom-built adapter. The head-neck systems were oriented at 45° offsets relative to the midsagittal plane for oblique extension and oblique flexion (Fig. 1). Tests were conducted at 3.4 m/s based on the U.S. Code of Federal Regulations (CFR), Part 571, Subpart B for the ES-2re dummy.

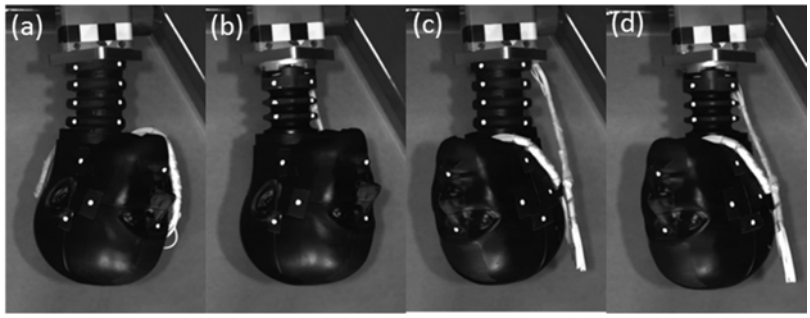

Fig. 1. Rigid arm pendulum configured for oblique extension, with the head attached to the (a) H3 and (b) ES-2 necks at a 45° offset relative to the midsagittal plane. Similar configurations were achieved with the (c) H3 and (d) ES-2 necks for oblique flexion tests. Inertial loads were applied toward the left.

III. INITIAL FINDINGS

Peak kinematics were affected by the neck surrogate used (Fig. 2). For oblique extension, the ES-2 neck led to a 67% increase in a_x (i.e. anterior-posterior motion) compared to the H3 neck. However, a_y (i.e. medial-lateral motion) exhibited a 5% increase with the ES-2 neck versus the H3 neck. For oblique flexion, both a_x and a_y increased by 27% with the ES-2 neck. Head angular measures also increased with the use of the ES-2 neck compared to the traditional H3 neck. Under oblique extension, the ES-2 neck allowed a 17% higher α_x (i.e. coronal plane rotation) and 38% higher α_y (i.e. sagittal plane rotation) compared to the H3 neck. Furthermore, α_x and α_y increased by 44% and 48%, respectively, during oblique flexion.

M. Begonia (tel: +1 414 3842000 x41399; e-mail: mbegonia@mcw.edu) is a Postdoctoral Fellow in the Department of Neurosurgery, and F. A. Pintar and N. Yoganandan are Professors, all at the Medical College of Wisconsin, Milwaukee, USA.

TABLE I
COMPARISON OF PEAK LINEAR AND ANGULAR ACCELERATIONS UNDER OBLIQUE LOADS.

Case	Neck	a_x (G)	a_y (G)	α_x (rad/s^2)	α_y (rad/s^2)
Oblique Extension	H3	7.95	9.20	2032.35	2013.45
	ES-2	13.25	9.65	2809.48	2350.94
	Ratio (ES-2/H3)	1.67	1.05	1.38	1.17
Oblique Flexion	H3	12.27	8.86	1854.08	1783.63
	ES-2	15.54	11.28	2749.95	2576.93
	Ratio (ES-2/H3	1.27	1.27	1.48	1.44

IV. DISCUSSION

The ES-2 neck increased linear and angular head kinematics under oblique loads. These results likely correlate with the distinct characteristics of each neck. The H3 neck has an asymmetrical design and connects to the head using a pin inserted medially/laterally through the neck's nodding joint and a complimentary head adapter [9]. This head-neck complex yielded lower kinematic measures since it was tightly coupled and experienced a stiffer lateral response compared to its flexion/extension response. Conversely, the ES-2 neck has a symmetric design with its endplates connected to the central molded section with neck buffers instead of a pin [10]. This head-neck complex yielded higher head kinematics since it was less tightly coupled and allowed similar ranges of both medial/lateral and anterior/posterior neck motion, most likely due to its symmetric geometry. This observation is based on previous work which showed that unlike the Hybrid III neck, the Hybrid II neck experienced a similar bending stiffness under flexion, extension and lateral bending due to its symmetric design [9]. As neck kinematics differ under frontal versus lateral conditions, the H3 neck may not be ideal for all loading cases. This is important considering that the stiffness of the dummy head-neck complex affects impact direction and severity [3].

Preliminary results indicate that the head-neck complex behaves as a less rigidly coupled system with the ES-2 neck than with the H3 neck under oblique loads. An ES-2 neck may be advantageous for achieving higher angular measures in helmet evaluations to ensure that susceptibility to brain injury is not underestimated given the lateral stiffness of the H3 neck. Peak measures were low in this study due to the lack of direct impacts to the head, but the neck influence was evident. Conventional helmet assessments involve a drop tower apparatus with a headform, rigidly fixed to the carriage, and the pass/fail criteria are typically based on a peak linear acceleration threshold. However, other helmet testing methods such as the NOCSAE linear impactor standard use a neck to evaluate the rotational kinematics of the head thus allowing the use of rotation-based injury metrics. Conventional helmet tests should be supplemented with a measure of angular kinematics, and an effective way to achieve this is through the incorporation of a neck. While the apparatus used in this study differs from traditional test rigs, the results can be transferred directly to gain insight on head kinematics prior to direct helmet impact as the head is likely to experience linear and rotational motions. Another transferrable aspect of this work is the head-neck complex itself since it can be incorporated into multiple test rigs including drop towers and linear impactors. Finally, this method could be used to analyze helmet/head decoupling that could be initiated by inertial loading prior to helmet impact.

V. ACKNOWLEDGMENTS

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