In-vivo Measurement of Head-Neck Reflex Responses to Multi-directional Accelerations

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I. INTRODUCTION

Low-speed rear-end vehicle collisions often produce neck injuries which are painful for individuals and costly to society [1]. Passengers of self-driving cars may be subject to different patterns of whiplash injury due to the novel seating arrangements and activities afforded by the technology. Although computer head-neck models have been developed to simulate head-neck movements during rear-end collisions [2-4], few have been compared to in-vivo recordings of lateral accelerations. Most experiments have examined rear or frontal accelerations [5-8], with few experiments [9] including other directions.

We extend the work in the literature by recording the three-dimensional (3D) kinematics and muscular activity of the neck in response to sudden accelerations from four different directions (forward/backward/left/right) during mechanically simulated* driving manoeuvres in a real vehicle. We are using OpenSim [11] and a modified version of Mortensen et al.'s [11] head-neck model to evaluate joint kinematics so that our measurements can be more easily used to validate human body models (HBMs). In this work, we evaluate the quality of our modified version of Mortensen et al.'s [11] model by comparing measured optical marker locations to the corresponding locations on the model.

II. METHODS

Recordings of the kinematics and muscular activity of the head and neck were taken from 21 participants (11 female) during simulated driving manoeuvres at the FKFS (https://www.fkfs.de/en/test-facilities/driving-simulator/stuttgart-driving-simulator) mechanical driving simulator in Stuttgart (Fig. 1A). The positions of 15 infrared reflective markers placed on the head, neck and shoulders were recorded by 6 OptiTrack (USA) cameras as the participant was accelerated in one of four directions (forward/backward/left/right) at magnitudes of up to $5 m/s^2$ (Fig. 1B). Accelerations were applied in each direction in a randomized order with a randomized delay (1-5 min.) between each trial. Surface electromyographic (EMG) activity from the sternocleidomastoid, upper and lower trapezius were recorded using the Biopac MP 160 system (USA) (Fig. 1B). The ethical committee of the University of Stuttgart approved this study (Az 22-001).

Due to both the seatbelt and the challenging sight lines we were not able to record motion capture markers from the torso. To reconstruct the torso's position, we attached the pelvis of Mortensen et al.'s [11] model to the seat using a spherical joint to approximate the relative movement between the participant and the seat. The 3D pose of the model was reconstructed using OpenSim's inverse kinematics (IK) algorithm. To evaluate the quality of both the model and the IK reconstruction we calculated the difference between measured and simulated marker positions.

III. INITIAL FINDINGS

The virtual and measured marker positions are similar except during lateral accelerations (Figs. 1D and 1E). During lateral accelerations, the model's acromion marker can differ in its vertical coordinate (Z) by more than 3cm (Fig. 1F) during the near-side acceleration, and by more than 6cm during the far-side acceleration. We plan to reduce this error using an articulated lumbar spine model and/or scapulothoracic joints to the model.

IV. DISCUSSION

One of the strengths of our measurements is that we have simultaneously recorded the 3D movements of the bony landmarks of the head and shoulders and recorded normalised EMG responses from major neck flexors and extensors. When validating an HBM it is important to have the initial pose of the model as well as the timing and strength of the reflex response. All these factors have a large influence on the movement of the head, yet few experiments have measured these quantities.

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Our study design has three limitations in terms of its utility for validating HBM models: surface EMG rather than intramuscular EMG was used; participants were tested in a real vehicle; and accelerations were limited to 5 m/s^2. We elected to use surface EMG for our measurements because it is less invasive for participants. The disadvantage is that our measurements cannot report on the activity of the neck's many deep muscles. Since we recorded participants in a real vehicle our measurements include head-headrest contact and large lateral body movements that may complicate the process of validating a neck model. Finally, we were limited to using accelerations on the order of 5 m/s^2 which is lower than other studies [5-9] and far below the accelerations that cause injury. Despite these limitations, our data are useful for tuning and validating the response of HBM neck models to multi-directional accelerations. Once complete, our dataset will be the first publicly available data set that includes both head-neck kinematics and muscle activity in response to multi-directional accelerations.

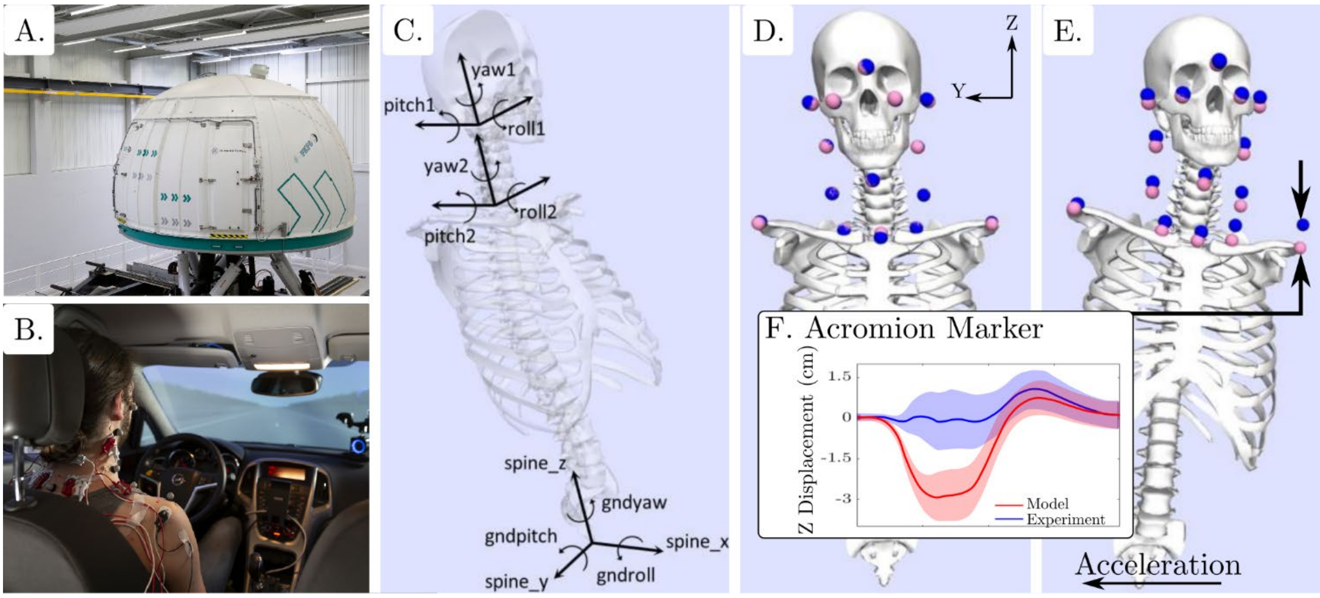

Fig. 1.: Driving manoeuvres were mechanically simulated at the FKFS in Stuttgart (A.). Inside the dome the movements of the participant were recorded using an OptiTrack system (USA) while the electrical activity of six of the participants' neck muscles were recorded using a Biopac system (B.). After the experiment, a modified version of Mortensen et al.'s model [11] was used to calculate the joint kinematics of the head-neck model (C.). The model tracks the movements of the recorded markers well except during lateral accelerations (D. initial posture, E. peak displacement) when the acromion marker error exceeds 3cm (F.).

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