Neck Muscle Activation and Posture of a Human Subject during simulated Rollover Trajectories

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I. INTRODUCTION

Despite improvements in vehicle safety and stability, motor vehicle rollovers remain dangerous events that can cause catastrophic cervical spine and spinal cord injuries [1]. To develop effective countermeasures, the occupants' pre-impact state needs to be known. Previous experiments have exposed human subjects to quasi-static inversions [2], isolated rotations [3–5], pre-trip kinematics including lateral accelerations and small roll angles (<16°) [6], or inverted freefalls [7]. As these isolated conditions rarely exist in real-world rollovers, we developed a robotic device that i) simulates the rollover's yaw, trip, and first half roll based on data from a staged rollover [8], ii) reproduces these rollover kinematics with high repeatability, iii) is safe for human subject use, and iv) enables the collection of occupant posture and muscle activation data throughout the trajectory [9]. The goal of this preliminary study was to simultaneously acquire neck muscle activation and posture data during the simulated rollover in a single human subject.

II. METHODS

One healthy female (30 years old) participated in this experiment, which was approved by the University of British Columbia's Clinical Research Ethics Board. The subject sat in an automotive racing seat (Kirkey Racing Fabrication INC., St. Andrew's West, ON) fixed to the robot's end effector (Fig. 1) and was secured by a 5-point harness (RCI Racers Choice Inc., Tyler, TX) and snowboard bindings. The subject's arms were strapped to their thighs. Neck muscle electromyography (EMG) was recorded using indwelling electrodes (0.05 mm Stablohm 800A, California Fine Wire Company, Grover Beach, CA) inserted under ultrasound guidance (MicroMaXX, Sonosite Inc., Bothell, WA) bilaterally into the semispinalis capitis (SSCAP), splenius capitis (SPL), and sternocleidomastoid (SCM) muscles. The electrodes were placed near the centre of each muscle's horizontal cross section at the C4/C5 level. Surface electrodes (H69P, Medtronic, Dublin, Ireland) were used for the sternohyoid (STH) muscles and for the reference electrodes on the sternal end of the clavicle. Raw EMG signals were amplified (x200), bandpass filtered (indwelling: 50-2000 Hz; surface: 50-500 Hz, 60 Hz notch) and sampled at 10 kHz. The root mean square (RMS, 20 ms window) of all EMG signals were normalised by the maximum value of similarly processed EMG data acquired during maximum voluntary isometric contractions (MVICs) and expressed as %MVIC. The orientations of the head, chest and seat relative to the lab were determined from active infrared emitting diodes (IREDs) collected at 100 Hz using an optical measurement device (Optotrak Certus, Northern Digital Inc., Waterloo, ON). The 3D orientations of the head relative to the seat, the head relative to the chest, and the chest relative to the seat were then calculated when the seat was inverted (roll angle = 180°). A high-speed video camera (V1212, Phantom, Wayne, NJ; AF NIKKOR 24-85 mm lens, Nikon, Tokyo, Japan) recorded a frontal view of the subject at 200 Hz.

We exposed the subject to six trials of the same rollover trajectory (Fig. 2, top right). In the first two trials, the subject was instructed to relax before motion onset and maintain a forward-looking gaze without further instructions. In the following two trials, the subject was instructed to brace before motion start and to resist the rollover perturbation. In the last two trials, the subject was instructed to keep their muscles inactive throughout the trial. The order of the rollover trials was not randomised to preserve the first relaxed and unpracticed trial. To minimise habituation, trials were separated by 10 to 20 minutes.

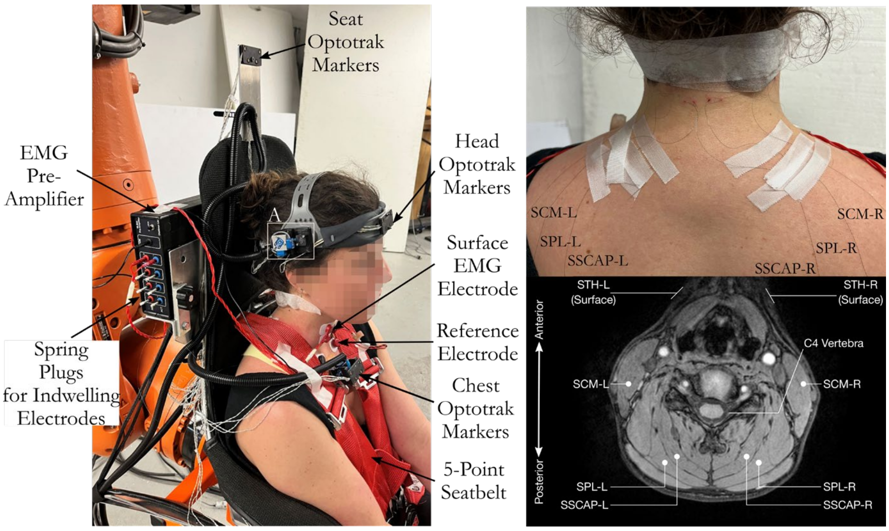

Fig. 1. Left: experimental, electromyography and Optotrak marker setup. Top right: wire electrodes after insertion. Bottom right: exemplar transverse magnetic resonance image of a neck at C4 level with indwelling wire electrode insertion locations.

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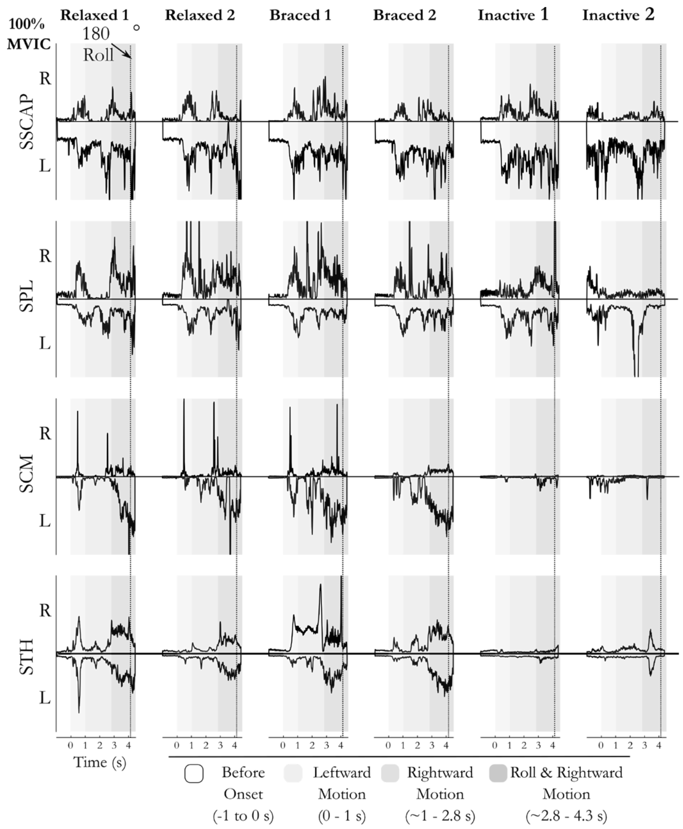
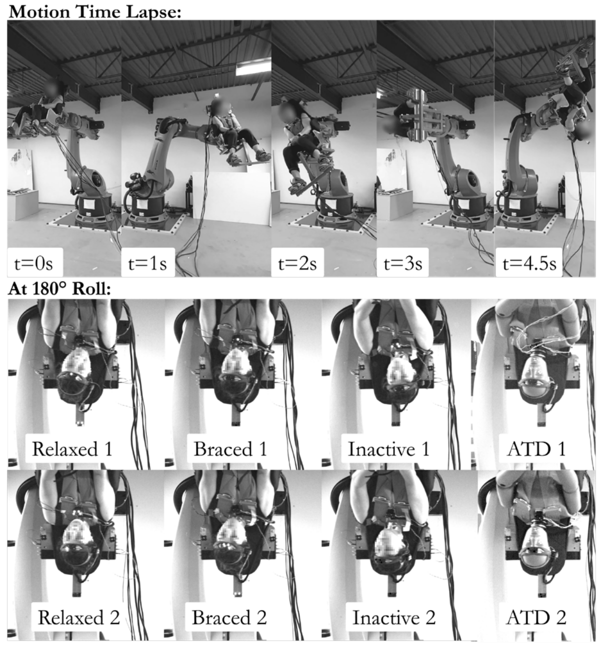
III. INITIAL FINDINGS

The subject activated all muscles during the rollover trials (Fig. 2, left). Peak muscle activation ranged from 3 %MVIC (SCM-L, Inactive 2) to 222 %MVIC (SPL-R, Braced 2). Muscles generally activated in a characteristic pattern that consisted of two or three peaks: one immediately after motion onset (with symmetric muscle activation), and one to two more after the change in lateral direction and/or during the roll motion. While muscle activation amplitudes in the relaxed and braced trials were similar, there were reduced activity levels in the inactive trials, especially in SCM and STH. At the time of full inversion, we observed a range of relative orientations between head and chest, chest and seat, and head and seat with no clear pattern in relative orientation either between or within conditions (Fig. 2, bottom right). Relative roll angles of the head showed the largest differences between trials, with head-to-chest angles of -9° to 21° and head-to-seat angles of -18° to 7°.





Relative Angle (°)	Head relative to seat			Head relative to chest			Chest relative to seat		
	Roll	Pitch	Yaw	Roll	Pitch	Yaw	Roll	Pitch	Yaw
Relaxed 1	-18.3	-10.1	11.3	-9.0	1.0	13.5	-9.1	-10.7	-3.9
Relaxed 2	-3.9	-16.5	6.4	11.7	6.6	18.9	-14.9	-25.0	-7.8
Braced 1	-5.2	-13.5	-1.2	7.5	-0.4	5.4	-12.9	-13.8	-4.8
Braced 2	-12.1	-12.8	5.1	-1.7	-5.6	11.2	-11.0	-7.1	-6.2
Inactive 1	7.2	-6.6	-1.1	21.0	-0.3	13.7	-13.5	-11.2	-11.6
Inactive 2	6.4	-24.0	-11.2	9.9	-19.8	4.4	-8.5	-7.2	-13.2

Fig. 1. Left: comparison between right (R) and left (L, data inverted) muscle activation before and during the rollover. Muscle activation is expressed as percent maximum voluntary isometric contraction (%MVIC). The vertical axis (both directions) is 100%MVIC. Shaded areas indicate the phases of the rollover trial. The dotted line shows the time when the seat was inverted (180° roll angle). Right (top to bottom): (i) time lapse images of the rollover, (ii) video frames at the moment of full seat inversion, with the 4th column showing the same frame with a 50th %ile male HIII ATD for comparison (no Optotrak data collected), and (iii) a table of relative orientations between seat, head and chest (roll-pitch-yaw decomposition).

IV. DISCUSSION

Measuring muscle activation bilaterally may help explain head posture asymmetries, which could account for the high frequency of unilateral fractures (66% [10]) that require some degree of lateral neck bending. Although limited to a single subject, left lateral neck bending and asymmetric activation in SCM had developed at the time of seat inversion, which may coincide with a potential roof impact (Fig. 2, right). Moreover, this lateral bending was most pronounced in the first trial wherein subjects were initially relaxed. Of the trials performed here, this first trial may best represent a naïve real-world occupant in a rollover crash. Despite testing only a single subject in a single rollover condition, these preliminary results show a range of responses within a single individual, some of which may be more injurious than others, and highlight some differences between human and ATD responses. Tests of more subjects will be conducted, as they are needed to better quantify the head and neck dynamics during impending headfirst impacts in rollover crashes.

V. REFERENCES

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