Characterisation of Driver Evasive Postures During Quasi-Realistic Collision Events

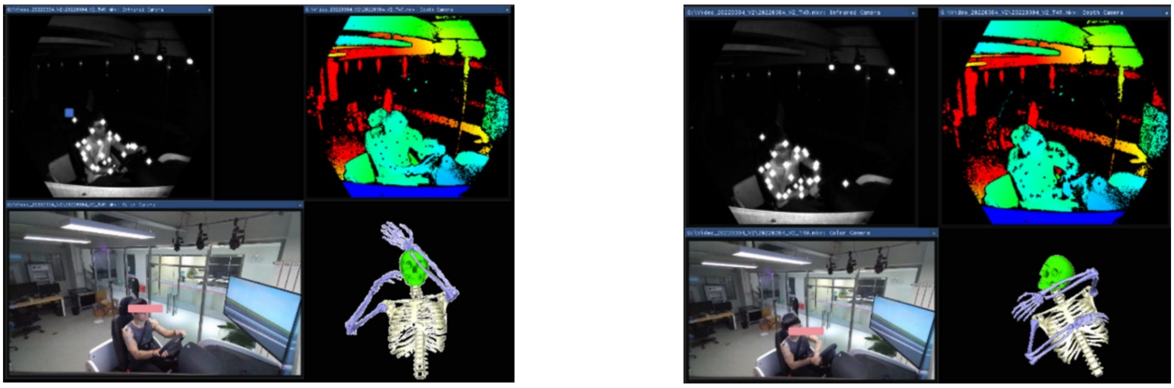
Zihe Zhao, Gaoyuan Kuang, Tainle Lu, Qing Zhou, Bingbing Nie, Gregory Tierney, Shi Shang*

I. INTRODUCTION

Pre-crash driver posture is a critical factor affecting injury severity, since it governs the body's response and interaction with restraint systems during impact, leading to different injury patterns[1–2]. Current studies on driver out-of-position (OOP) postures mostly focus on several typical cockpit postures. However, such postures are usually generated by manually adjusting a small number of parameters, such as seatback angle to simulate forward/backward leaning or upper-arm/forearm angle to replicate steering arm postures. These methods rely on discrete static postures and lack support from real-world crashes or large-scale naturalistic driving data[1][3]. During collisions, drivers' instinctive emergency behaviors produce complex dynamic posture changes[4–6], which alter load distribution and force transmission. Consequently, injury risk assessments based on static standard postures can be inaccurate. This study aims to reconstruct the full dynamic evolution of driver posture during collisions using motion capture, establish quantitative links between pre-crash behavior and injury outcome, and improve the realism and generalisability of crash simulation for injury risk evaluation.

II. METHODS

Driving simulation experiments were conducted to investigate drivers' emergency responses and characterise their collision (C) postures under quasi-realistic scenarios[7]. A motion capture system combined with depth cameras was used to record full-body kinematics. Valid cases were defined as frontal collisions between the host vehicle and another vehicle. Among 240 trials, 115 valid cases were retained for analysis, as only trials with virtual collision events were deemed valid, while those without such events were excluded. Given that head motion strongly influences injury response, the standard OpenSim musculoskeletal model was modified. The head and neck were decoupled, and three additional rotational DOFs (lateral bending, flexion-extension, axial rotation) were added to better reproduce real driver posture and enhance the biofidelity of subsequent crash simulations. Figure 1 illustrates the comparison between a driver's normal driving posture and collision evasive posture, both reconstructed via a motion capture system and inverse kinematics in a driving simulation experiment.



(a) Normal driving posture (b) Collision posture

Fig.1 An illustration of driver posture comparison (normal vs. collision) reconstructed via motion capture and inverse kinematics in a driving simulation experiment

III. INITIAL FINDINGS

In this study, the full trajectory of driver postural adjustment was captured via motion capture, covering normal driving, evasive response to hazardous events, and post-collision posture stabilisation. The kinematic data

S. Shang (email: SShang@bjfu.edu.cn; tel: +86-13693583025) is an Assistant Professor and Z. Zhao is a MSc student in the School of Technology at Beijing Forestry University, China.K. Gao is a MSc student, T. Lu is a PhD student, B. Nie is an Associate Professor, and Q. Zhou is a Professor in the School of Vehicle and Mobility at Tsinghua University, China. G. Tierney is an Associate Professor in the School of Engineering at Ulster University.

were mapped onto a customised OpenSim human musculoskeletal model. Results show that drivers exhibit body inclinations and torsions of varying amplitudes when facing hazardous stimuli. Trunk motion was quantified using the three-DOF angular variations of the lumbar spine. Figure 2 shows the postural variation corridor for a representative case. The posture of the driver at the moment of impact is defined as the collision (C) posture. Angular deviation (δ) is defined as the joint angle difference between the collision (C) posture and the normal (N) posture at impact to quantify postural changes. The distribution of δ across 115 cases for representative upper limb and spinal joints (including the elbow and spinal joints) is presented in Fig. 3. Elbow joints (efl, efr) exhibit large positive δ values, indicating significant flexion during evasive responses, while lumbar joints show moderate deviations with high inter-individual variability, particularly in rotation.

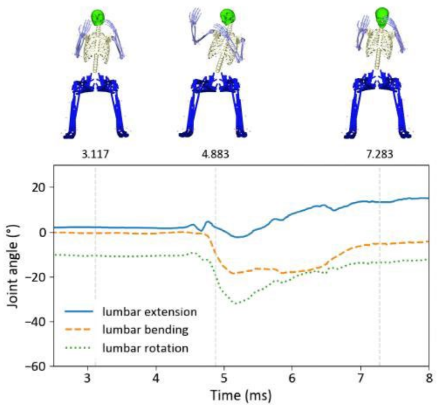


Fig.2 Lumbar angle time histories in a representative test case.

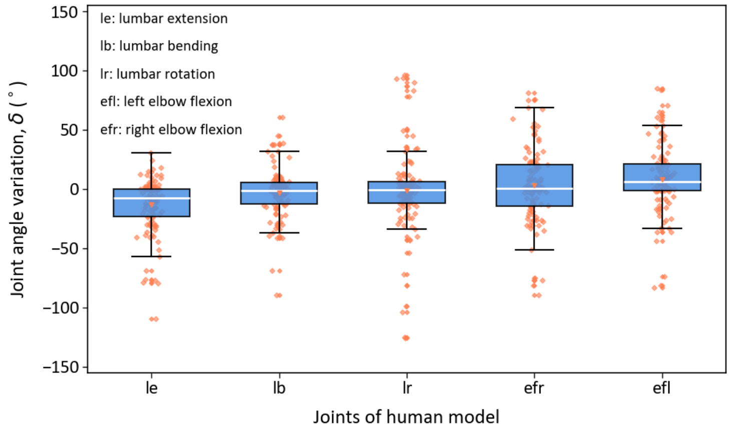


Fig.3 Distribution of joint angular deviations (δ) across 115 test cases.

Wilcoxon signed-rank tests were performed to evaluate the significance of angular deviations under different collision scenarios. Results confirm that significant postural changes occur during collisions ($p < 0.05$), and their magnitude and distribution depend on collision type. Postural responses are not fixed patterns; they emerge as evasive behaviors shaped by the driver's adaptation to the specific collision environment. Postures were mapped to the Madymo Hybrid III dummy model. Given the high complexity and heterogeneity of C postures, four representative postures were selected for simulation: left leaning, right leaning, forward tilting, and backward tilting, based on dominant lumbar motion. Injury severity was assessed using HIC_{15} and CTI. Paired simulations (C posture vs. N posture) were run for the four representative postures. In all cases, HIC_{15} and CTI values under C posture differed from N posture in both magnitude and trend. This demonstrates that C posture significantly modulates injury metrics, by altering the body's interaction with passive safety systems (airbag, seat belt, seat) and the load transmission path of the musculoskeletal system.

IV. DISCUSSION

From the perspective of the collision event corridor, the human body moves continuously from visual stimulus detection to the end of impact. Evasive behaviors cause rapid upper-body displacement and multi-joint angle variation, with the elbow and lumbar spine showing the largest ranges. Statistical analysis of δ shows that, compared with the normal posture, the elbow flexes significantly (mean: 23°), lumbar rotation averages 22°, and left arm rotation averages 19°. Rotational motion is thus a non-negligible component of realistic collision postures. Including such motions improves the biofidelity of injury analysis.

Compared with conventional OOP or manually defined static postures, this study incorporates drivers' natural emergency responses, providing more realistic and detailed human postures and complete posture sequences for studying driver responses to hazards. Using these reconstructed C postures as inputs enhances crash simulation fidelity. The proposed pipeline of OpenSim posture reconstruction and Madymo injury simulation provides a practical framework for biologically realistic vehicle safety assessment.

V. REFERENCES

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