Assessing the influence of parameter variation on kinematic head injury metric uncertainty in multibody reconstructions of real-world pedestrian vehicle and ground impacts

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I. INTRODUCTION

Traumatic brain injury (TBI) in road traffic collisions (RTCs) is a significant problem. Approximately 34 million people sustain a TBI worldwide each year [1]. Of the global fatalities, 22% are pedestrians [2]. Head injury is the leading cause of death and serious injury among pedestrians [3]. In-depth collision databases contain both collision and clinical information. They are a valuable tool for understanding how collision biomechanics relate to specific injury pathologies. Specific pathologies relate to different mechanisms [4]. Computational modelling is an efficient, valuable tool for investigating injury mechanisms. Multibody (MB) models have been widely used for vulnerable road user reconstructions [5]. There is some investigation into the ability of MB models to predict ground impact in pedestrians [6]. We adopted a rigorous approach, with parametric sweeps, to reconstruct pedestrian/car collisions using MB. We explored the effects of uncertain parameters on head kinematics.

II. METHODS

We selected pedestrian cases from the UK Government's Road Accident In-Depth Studies (RAIDS) database (with and without TBI) [7]. RAIDS contains >5000 subjects involved in >2000 collisions. There are 150 pedestrians involved in collisions within this data, with the majority seriously or fatally injured [8]. We reconstructed six cases using multibody dynamic modelling (Madymo) software. Only a validated, scalable male pedestrian model was available in Madymo, leading us to select male pedestrians with a range of TBIs. The vehicle model is made to be geometrically accurate, with contact characteristics defined from literature [9-10]. The contact is defined with a force-deflection curve. The head-ground characteristics are modified according to Yoganandan *et al.* (1995) [11], as seen in literature [12]. Evidence from RAIDS, e.g. vehicle damage profile, CCTV (where available), is used to recreate the pre-collision scenario in a virtual environment. We varied parameters which evidence could not fully constrain, such as: pre-impact stance (shown); vehicle and pedestrian speeds; relative pedestrian-vehicle position; height and weight of the pedestrian. This created 636 different scenarios. Literature head kinematic threshold values were used to compare the average values to true TBIs sustained.

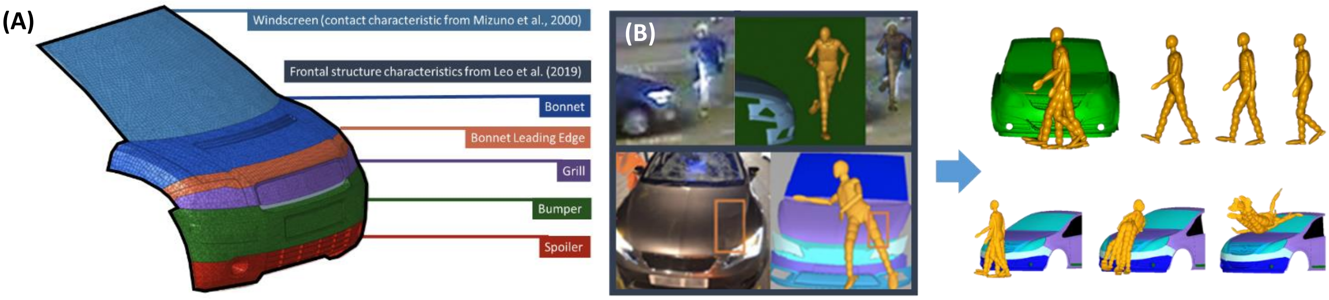

Fig. 1. Methodology for the virtual modelling. (A) The FE vehicle model has accurate front-end geometry and is segmented by region. Different contact characteristics representative of the vehicle are applied from Mizuno *et al*. (2000) and Leo *et al*. (2019). (B) An example of pre-impact positioning of the pedestrian model using CCTV footage evidence.

III. INITIAL FINDINGS

Pedestrian-vehicle contact points were accurate throughout compared to physical evidence, such as crush damage marks and swipe marks. In general, there is significantly less variation for the head-windscreen impact than the head-ground impact, as can be seen in Fig. 2. F and G are the same case, with the scenarios in F and G being reconstructed using the 50th and 95th percentile adult male pedestrian models, respectively. In this case, there was greater variation for the 95th percentile model. An exploration conducted of the contact force for case C showed that there are differences in the biomechanics at ground impact that can be grouped according to ground contact force differences. It is possible to further constrain the metric values, eliminating scenarios that do not match the investigator-measured pedestrian throw distance. Higher average simulated metric values corresponded to more severely injured pedestrians. Intracranial haemorrhage (ICH) was correctly predicted with rotational acceleration during windscreen contact alone in cases A, C, F and G, which were above the commonly accepted 10 krad/s^2 threshold [13-14]. Pedestrian E also sustained an ICH (9.6 krad/s^2, just below threshold). Pedestrians B and D did not sustain TBI and had low windscreen-head kinematic injury metric values.

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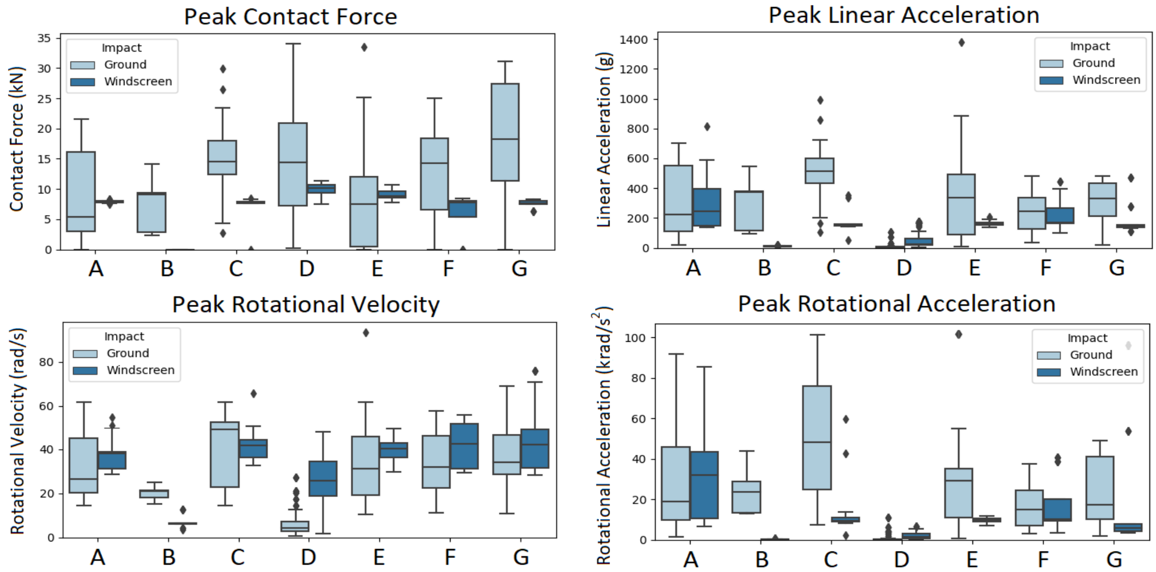

Fig. 2. The average and distribution of peak head kinematic metric values are shown for seven reconstructed pedestrians. Ground contact (light blue) and windscreen contact (dark blue) are shown (where applicable). We included 636 scenarios.

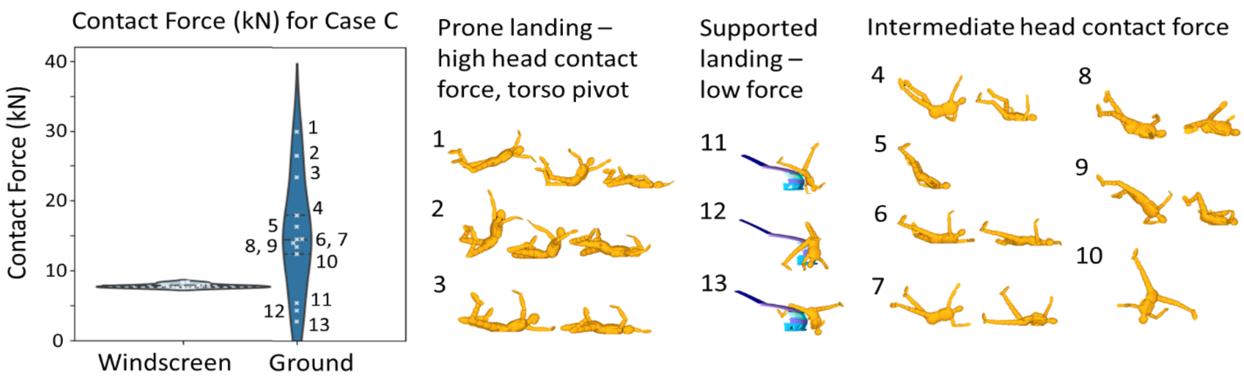

Fig. 3. Peak head contact force is shown for case C, which had CCTV footage available. The contact force relating to the windscreen impact is well constrained around 8,000 N, ranging 500 N either side. There is a much greater range of ground contact force, from around 2,500 N to 30,000 N. Ground landing mechanics are shown on the right, corresponding to labelled ground impact force. The landing biomechanics relates to peak head contact force, ranging from highest to lowest: prone with contact-induced rotation about the hips (1-3), supine or limb-led (4-10), vehicle-supported landing (11-13).

IV. DISCUSSION

Head kinematic values were well constrained for the head-windscreen strike, showing the small effect of uncertain parameters on the predictions and thus usability of MBs for reconstructing the events. There was, however, large variation in head kinematic values for head-ground impact. Existing work shows Madymo's ellipsoid pedestrian model had limited injury prediction capability and demonstrated considerable differences in the ground contact kinematics of cadaver-vehicle collisions [6]. CCTV was available for cases C and E. Comparing simulated kinematics to CCTV footage in C showed that the latter part of the pedestrian throw phase, and consequently ground contact, were not well reproduced, supporting existing findings [6]. As the windscreen interaction was almost universally less severe, the windscreen values were taken as a minimum severity indication. It was possible to well predict ICH from the rotational windscreen contact kinematics alone in all but case D, which was borderline. This study adds a small number of rigorously reconstructed real-world pedestrian-vehicle impacts. It also raises understanding of the limitations relating to ground contact in commonly adopted MB modelling tools.

V. REFERENCES

[1] Dewan, M. C., *et al.*, *J Neurosurg*, 2018.
[2] World Health Organization, 2013.
[3] Zhang, G., *et al.*, 52nd AAAM Conference, 2008.
[4] Kleiven, S., *Front Bioeng Biotechnol*, 2013.
[5] Ramamurthy, P., *et al.*, *Int J Crashworthiness*, 2011.
[6] Shang, S. *et al.*, *Accid Anal Prev*, 2021.
[7] RAIDS database, UK Government, accessed 2022.
[8] Baker, *et al.*, *Brain commun*, 2022.
[9] Mizuno & Kajzer, SAE Technical, 2000.
[10] Leo, *et al.*, *IRCOBI*, 2019.
[11] Yoganandan, *et al.*, *J Neurotrauma*, 1995.
[12] Posirisuk, *et al.*, *Accid Anal Prev*, 2022.
[13] Depreitere. B., *et al.*, *J Neurosurg*, 2006.
[14] ECE 22.06, UNECE Regulation, 2021.