Computational Investigation on Rider Kinematics of Electric Two-wheel Vehicles in Collision with Car

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I. INTRODUCTION

Electric two-wheel vehicles (E2W) have become newly popular emission-free transportation tools in China given its convenience and economy [1]. Similar to cyclists or motorcyclists, E2W riders are considered as vulnerable road users (VRUs) due to their high injury risk in collision with cars on the road [2]. Rider kinematics play an important role in the resultant injury patterns [3]. Despite the existing studies on pedestrian and cyclist safety, relatively little is known about the kinematical response of E2W riders. Therefore, the goal of the present study is to investigate the rider kinematics and the influencing factors in car-E2W collisions using computational biomechanical analysis.

II. METHODS

A multi-body E2W-car model was developed consisting of a rider, an E2W and a small-sized sedan to simulate the rider kinematics in a collision event under MADYMO environment (Fig. 1a). The E2W model was developed based a representative E2W brand XiaoDao in China, with the geometry and mass distribution precisely replicated. The model consists of four rigid bodies, i.e., the front wheel, the rear wheel, the main body and the battery, which are connected by mechanical joints. The 50th percentile male pedestrian model incorporated within MADYMO [4] was selected as the rider, which consists of 52 rigid bodies and 52 joints. The anthropometry of the rider was varied via scaling in the model validation and parametric study. One representative sedan model in China, i.e., the Volkswagen Golf, was used in the collision analysis. The detailed front-end geometry was reconstructed, and the stiffness definition was estimated from existing literature.

Model validation was performed using detailed information of a typical real-world E2W collision accident in China (Fig. 1b). The developed model proved capable of replicating the rider kinematics as recorded by road cameras. Following this, a parametric analysis was conducted aimed to analyse how impact configurations affect E2W riders' responses. The parameters included impact velocity of the car (20-80 kph) and the E2W (0-30 kph), impact angle and offset between the car and the E2W, body size and seated height of the rider. To isolate the influence of each influencing factors, a baseline scenario was defined. Then each input value of the parameters was varied one at a time while the others were fixed (*one at a time (OAT)* method). This added up to 72 simulations for the whole matrix. The output rider kinematics were compared and analysed.

(a) (b)

Fig. 1. (a) Modeling setup of the vehicle-E2W-Rider collision scenario; (b) the selected real-world accident for model validation (image recorded by road camera).

III. INITIAL FINDINGS

Take the baseline collision with the car front-end for example, the lower extremities and the pelvis of the rider would first get contact with the bumper area. The upper torso then fell on the hood, leading to a wrapping motion of the whole-body on the car front-end. The head first made contact with the windshield or the rear part of the

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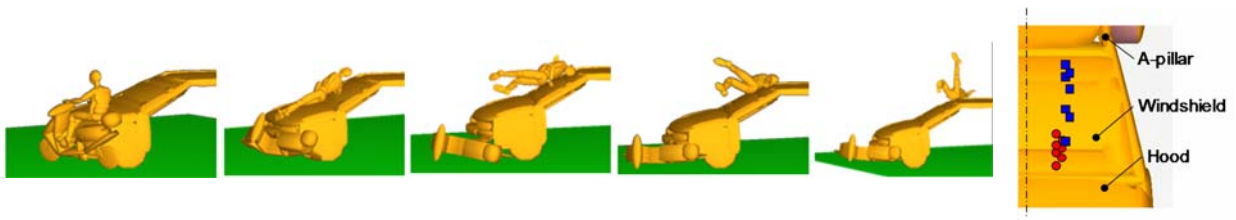
hood (Fig. 2a). For the investigated parameters, an increase of the car impact velocity resulted in an increase of the wrapping distance of the human body, regardless of body sizes. An increase of the E2W velocity would influence the head contact location in both the longitudinal and the horizontal directions relative to the car.

Body size exhibited significant effects on the kinematics during the crash. The small female usually got head contact at the frontal edge of the windshield; in contrast, the 95th percentile male got head contact more to the rear part (Fig. 2b). Besides, relative location of the rider and the car, and the rider posture prior to the event exhibited highly non-linear influence on the kinematical response. For example, with a 500 mm offset between the E2W of the car, the rider head would miss the contact with the car front-end, sustaining a high throw-out distance, eventually landing on the ground, which led to the ground making the main impact to the head.



(a) (b)

Fig. 2. (a) Typical kinematic response of the E2W rider in collision with car (shown: 40kph impact); (b) Contact locations of the rider head on vehicle front-end (shown: circle-small female, square-average male).

IV. DISCUSSION

Multi-body modelling provided a computationally efficient and biomechanically realistic approach to characterise the rider kinematics towards a better understanding of non-linearity and complexity of the crash event. Certain parameters (e.g., the impact velocity, relative impact location) influence the rider kinematics and the contact kinetics, which would further alter the resultant injuries. Compared to other VRU groups, such as pedestrians, the E2W riders sustained different kinematics, largely due to the high moving velocity of their own and the seated body posture prior to the crash. Also differently from the pedestrians, it is possible for E2W riders to wear protective devices (e.g. helmets) or have restraint systems (e.g. airbag-equipped E2Ws) to mitigate the increasing injuries.

Another comparison on kinematics is between the E2W and the conventional internal combustion engine powered two-wheel vehicles (e.g. motorcycles). The difference in geometry and mass distribution of the two-wheel vehicles could both contribute to the rider kinematics. Battery is the part with the highest mass in the E2W. As observed in some simulation case, the rider body wrapped around the front-end of the vehicle, leaving the E2W in the way front and get the vehicle stuck. Yet, more quantitative evaluation is needed to identify the effects resulted from the two-wheel vehicles. In addition, in-depth field investigation on the E2W rider specific kinematics and injury outcomes, when available, can be referred to prioritise the development of countermeasures.

Several limitations need to be noted. First, the multibody model approach provides a low computational cost and is relatively easy to implement, while with several simplifications on the structural characteristics of the car and the rider. The present results provided mostly a relatively comparison among the cases but are not appropriate for evaluation regarding the reported absolute value. Second, the parametric analysis is limited to the OAT method, which did not consider any combined effects of input parameters. Certain parameter may influence or interact with other parameters and so change the result, which requires further research efforts on a simulation matrix of larger scale and more advanced approach (e.g., the Latin hypercube method). Besides, larger number of simulations can also provide a basis for clustering the kinematics, the injury outcomes and initial conditions to better address the high non-linearity in the collision events.

In conclusion, these results form an initial part on a broader research project that focuses on identifying rider kinematics and injury mechanisms in collisions with a car front-end. It is anticipated to provide references in countermeasure design against E2W crash injuries.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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