Bicyclist Shoulder Forces in Car-to-Bicycle Crash and Single-Bicycle Crash Simulations

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I. INTRODUCTION

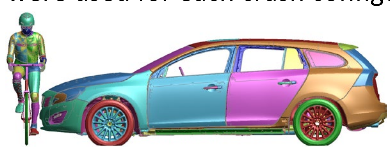
Cycling is recognized as a cheap and environmentally friendly mode of transportation, with the number of cyclists growing each year substantially [1]. Compared to the global status report on road safety 2013, the proportion of cyclist deaths has risen from 5% of all fatalities in 2010 to 6% in 2023, representing a 20% rise [2]. Many studies showed that bicyclists face high injury risks in both car-to-bicycle collisions and single-bicycle crashes [3,4]. Cyclists injured in a collision with a motor vehicle are generally more seriously injured, as head injuries being the most common [5]. However, fractures to the upper extremities are more frequent in collisions with other cyclists or in single-bicycle crashes and these injuries can often have long-term consequences [6]. Previous research investigated the injury mechanisms leading to shoulder injuries in single-bicycle crashes based on injury data obtained from hospital records [7,8]. As part of a wider project seeking to create a method to predict shoulder injury, we have started to look for impact configurations that will resulted the most severe shoulder impact and provided a challenge for potential protective countermeasures. Scanning configurations based on shoulder force is our method to converge on simulation and experimental test setups to be used in subsequent studies.

II. METHODS

The crash system model involved a mid-size station wagon car model and the SAFER HBM V10 positioned on the seat of a bicycle model to represent a 50th percentile male bicyclist. The shoulder forces were measured using “surface-to-surface contact” which was defined between the outer surface of the shoulder and car or ground/kerbstone. The shoulder injury evaluation was not included in this study. All simulations were performed using LS-Dyna (Version 971, R9.3.1 R140922, LSTC). The pre- and post-processing was performed using PRIMER Version 20.0 and HyperGraph Version 2022.

Car-bicycle Crash Simulations

The crash configuration is a bicycle (either stationary or moving straight-ahead at 15 km/h) impacted on the left by a car moving straight from a perpendicular direction at three different speeds (20, 40 and 60 km/h) (Fig. 1). Two pedal postures (vertical and horizontal) (Fig.2), representing high-low and front-rear lower extremity positions, were used for each crash configuration.



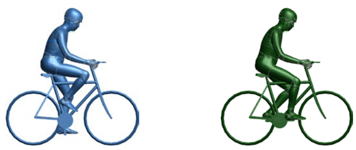


Fig. 1 Car-bicycle Crash configuration Fig.2 Two pedal postures (blue: vertical; green: horizontal)

Single-bicycle Crash Simulation

First, the system model was stationary, and under the effect of gravity, the tilt of the bicyclist resulted in a falling motion to the ground. Then, the impact simulations were conducted with a bicycle moving at 15 km/h hitting a square-edged rigid kerbstone which was mounted on the floor, three impact angles were used 90, 70 and 20 degrees, respectively (Fig. 3). The height of the kerbstone was 300 mm in the 90 degree impact and 150 mm in the 70 and 20 degrees simulations.

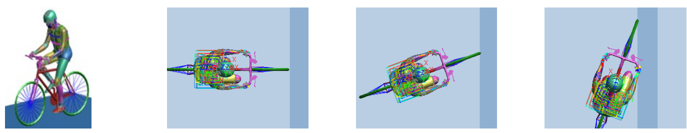


Fig. 3 Single-bicycle Crash configuration (from left to right: Stationary system model; Impact angle: 90 degree; Impact angle: 70 degree; Impact angle: 20 degree)

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III. INITIAL FINDINGS

In the car-bicycle crash simulations with a stationary bicycle, a higher car speed seems to generate a higher shoulder force, a forceful shoulder force was found with vertical pedal and a hit to the windshield. In the moving bicycle configurations, however, the maximum shoulder force was obtained for the lowest car speed (20 km/h) (Fig. 4), due to the elbow impacting the bonnet and the rider sliding sideways over the left edge of the bonnet, resulting subsequently in the shoulder impacting the ground.

A variation could be seen between the different pedal postures, the bicyclist with horizontal pedal posture experienced a lower shoulder contact point and more rotation of the torso of the upper body, resulting in a more moderate shoulder impact (except for the configuration with the car at 20 km/h) rather than a straight hit on the shoulder.

In the single-bicycle crash simulations, a tilt of the front wheel resulted in a falling motion to the side with the shoulder hitting the ground. However, the perpendicular impact (impact angle 90 degree) resulted in a falling motion over the handlebar with the head taking the initial hit to the ground before the shoulder. Despite the variation on bicyclist kinematics, it can be concluded that the moving bicycle with impact angle 20 degree generated a more forceful shoulder impact (Fig. 4).

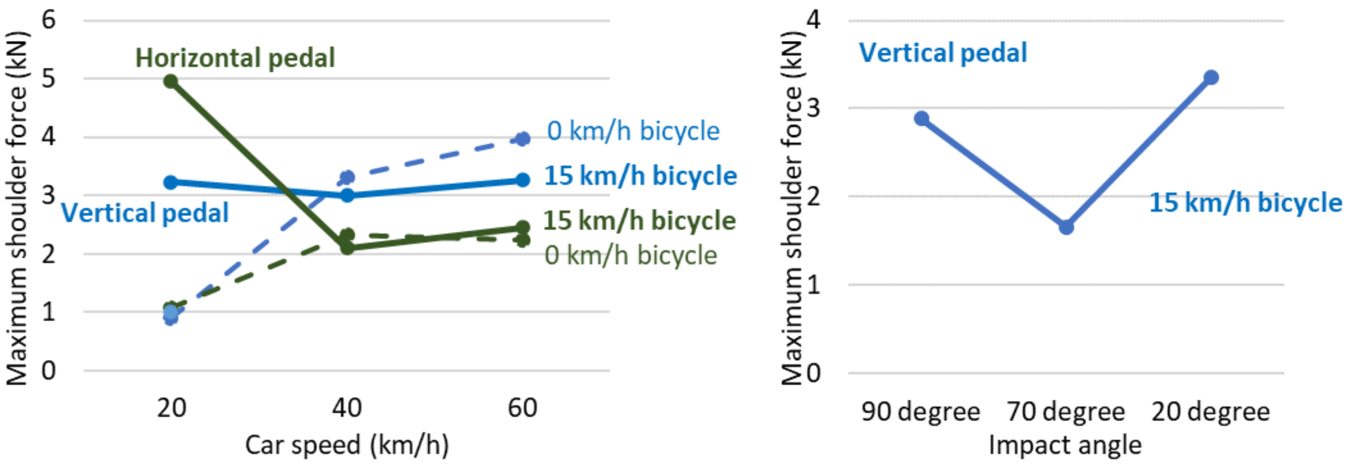

Fig. 4. Maximum shoulder force in car-bicycle crash(left) and single-bicycle crash (right) simulations

IV. DISCUSSION

The results give an insight into the shoulder force in car-to-bicycle crash simulations and single-bicycle crash simulations. The car with 20 km/h hitting a moving bicycle is the most severe configuration, with the most forceful shoulder impact resulting from the sideways falling motion to the ground. Compared with vertical pedal posture, the configuration with horizontal pedal posture might result in a more moderate shoulder impact. To be specific, the horizontal pedal posture leads to more rotation of the torso of the upper body (around the caudal-rostral axis), which then results in the contact point moving away from the lateral aspect of the shoulder after impact. As ideas for test configuration emerge from these potential options, the project will continue to validate findings with a physical surrogate, match those results in simulation and then explore the benefits of the updated SAFER HBM for predictions of bicyclist's shoulder injury risks.

Acknowledgment

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