Whole-Body Motion Category in Pedestrian-Vehicle Crashes Identified via Volunteer Tests and Publicly Available Videos

Quan Li, Shun Gan, Shi Shang, Taisong Cui, Qing Zhou, Bingbing Nie*

I. INTRODUCTION

Pedestrian fatality in vehicle crashes remains a global public health issue, accounting for 23% of the total number of road traffic deaths [1]. Many researchers have been studying pedestrian safety through real-world accident data analysis, PMHS tests and numerical modelling. In real-world road traffic accidents, however, pedestrians usually perceive danger and take natural avoidance actions prior to the impending collisions, which yields different kinematic features from the stationary setup of pre-impact motion in cadaver tests [2] and most mathematic simulations [3]. The pre-crash kinematics and posture significantly influence the injury risk and collision consequences [4]. Existing research on natural pedestrian behaviour (i.e. active response to emergency scenario) in traffic crashes is insufficient due to the inherent uncertainties and limited data resources [5-6]. To better understand the kinematic mechanisms during vehicle-pedestrian crashes in road traffic, we categorized and qualitatively described the pre-event motion and avoidance behaviour (if any) of pedestrians in parallel with an *in vivo* pedestrian volunteer experiment and real-world accident videos extracted from online resources. Furthermore, the experimental results will be used in quantifying the whole-body kinematics and as a reference in improved human body modelling and test setup for pedestrian safety purposes.

II. METHODS

Definition of pedestrian moving direction and vehicle front area

Considering the potential 6-DOF kinematics of the pedestrian in a traffic event, the orientation of the pedestrian avoidance motion was defined in terms of eight main directions at a 45-degree interval in front of the vehicle (Fig. 1). The relative location of vehicle to pedestrian, i.e. pedestrian approaching zone, intermediate zone and leaving zone, are defined based on pedestrian initial moving direction (represented with red point and solid arrow in Fig. 1) as well as the relative position of the pedestrian and the vehicle at the "collision" time.

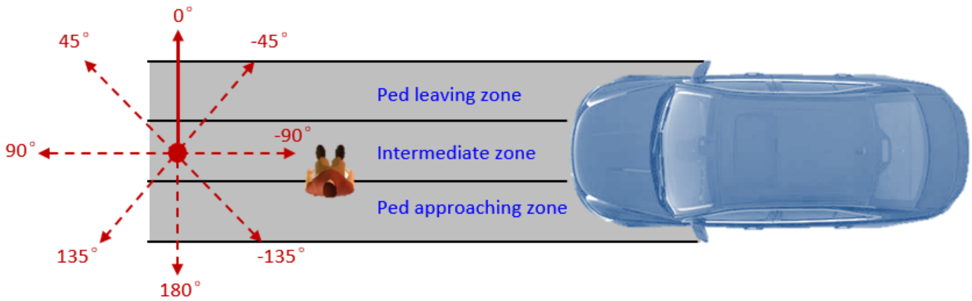

Fig. 1. Division of the vehicle front areas and pedestrian moving direction. The red point and solid arrow represent the initial location and moving direction of the pedestrian when he/she started to avoid the upcoming vehicle; the red dotted arrow represents the possible pedestrian avoidance directions thereafter.

Pedestrian volunteer experiment

We used a previously developed experiment platform based on immersive virtual reality (VR) technology to capture pedestrian behaviour [7-8]. A well-controlled dangerous traffic scenario, based on real-world accident videos, was used to stimulate the pedestrian ("subject") to react, i.e. engage in avoidance behaviour. We recorded the subjects' behaviour features and biomechanical signals during the subsequent natural responses. A total of 34 experiments (19 subjects) were completed and included in the data analysis.

B. Nie (e-mail: nbb@tsinghua.edu.cn; tel: +86-10-6278-8689) is an Associate Professor, Q. Li and S. Gan are PhD students, S. Shang is a Research Associate, Q. Zhou is a Professor in the School of Vehicle and Mobility at Tsinghua University, China. T. Cui is a researcher at Chongqing Changan Automobile Company Limited. Affiliations: State Key Laboratory of Automotive Safety and Energy, School of Vehicle and Mobility, Tsinghua University (B. Nie, Q. Li, S Gan, S. Shang, Q. Zhou); State Key Laboratory of Vehicle NVH and Safety Technology, Chongqing, China (B. Nie, Q. Li, T. Cui).

Accident video material

We constructed an accident video library consisting of public recordings or privately installed in-vehicle cameras shared publicly online (e.g. YouTube) for the purpose of extracting the whole-body motion category together with volunteer experiments. We screened out 100 videos based on the following criteria: (1) the pedestrian crossed the road while the vehicle came from one side of the pedestrian; (2) the pedestrian was adult; (3) the video was of sufficient quality to classify the avoidance behaviours. The materials come from different countries and regions (United States, Germany, Russia, China, etc.); we assumed that human behaviour when facing life-threatening situations are comparable across populations from different regions. Reactions of pedestrians were observed and analyzed based on the kinematic feature up to 2-3 s before and during the traffic event. In all cases, the direction of movement of pedestrians and vehicles is almost perpendicular. We defined pedestrian initial attitude posture is always 90 degrees to the car in this study.

III. INITIAL FINDINGS

Pedestrian motion in accident videos and experiments

The pedestrian motion trajectory and avoidance direction in volunteer experiments and image sequences of accident videos (Fig. 2) are compared for qualitative analysis. Fig. 2(a), 2(b) and 2(c) illustrate the pedestrian moved backward, moved forward and accelerated, stepped away to avoid the vehicle, respectively. A comparison of the image sequences shows that pedestrian avoidance behaviours in near-real VR environments and in real-world accidents are similar.

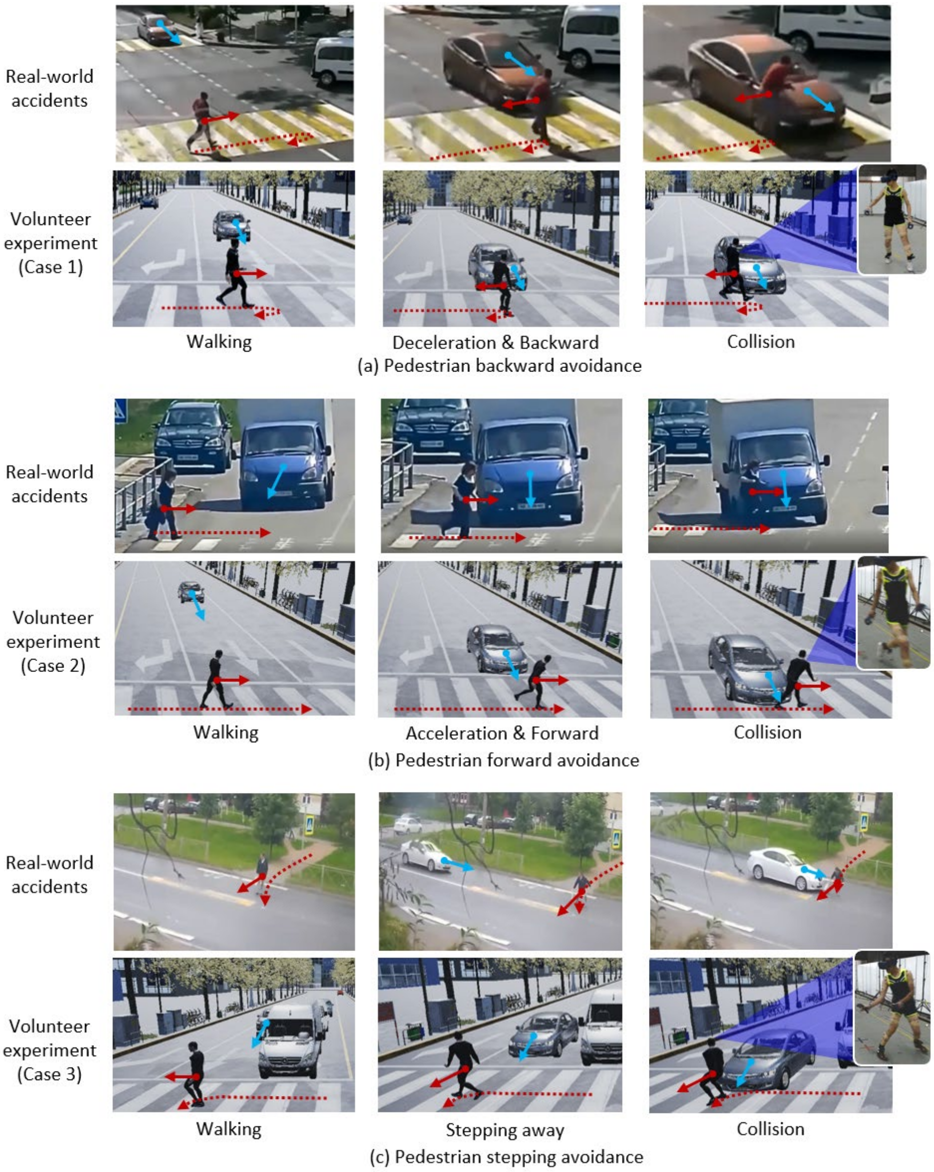

Fig. 2. Still shot of *in vivo* videos used to study pedestrian motion in car-pedestrian crashes. The red solid arrow and the dotted arrow represent the pedestrian's moving direction and trajectory, respectively; the blue arrow represents the vehicle's moving direction.

Motion categories of pedestrian

Pedestrian reactions were categorized into three groups: no reaction (48 cases in accident videos and 12 cases in volunteer test); horizontal avoidance movement (47 cases in accident videos and 22 cases in volunteer test); and vertical avoidance movement (jump off the ground, only 5 cases in accident videos).

"No reaction" (60 cases, 45%) This category represents pedestrians who were crossing the street without paying attention to their immediate environment and the threat posed by the vehicle. Consequently, they didn't perform any avoidance motion. This category's distribution was approximately half of walking pedestrians (58%) and half of running ones (37%).

"Horizontal avoidance movement" (69 cases, 51%) This category includes the cases where pedestrians recognized the vehicle's threat and tried to avoid the impending impact. The avoidance motion, in these cases, is horizontal and the corresponding direction could be determined by video analysis. No pedestrians performed an avoidance motion in the direction of the vehicle, which is in accordance with the human instinct of survival to avoid the impact. Therefore, only the results of the 0-180 degree avoidance motion are presented (Fig. 3).

For the 34 cases that occurred in the vehicle's pedestrian approaching zone (Fig. 3(a)), pedestrians tended to avoid the imminent collision by stepping away from the vehicle. In the intermediate zone, we observed a tendency by the pedestrian to correct their movement to a perpendicular direction of the origin (Fig. 3(b)). This is the direction of the vehicle and in many cases impact with the vehicle was unavoidable. With the vehicle front's pedestrian leaving zone, pedestrians mostly adjusted their avoidance motion to cross the vehicle front quickly (Fig. 3(c)). In addition, the results showed that most pedestrians appeared in the pedestrian approaching zone of the vehicle and tended to avoid it by stepping away, but this might be caused by the single designed traffic scene in the experiments. To better understand the influence of pedestrian motion state on avoidance direction, we divided these cases into two groups according to the pedestrian speed (Fig. 4). Due to the human body inertia during running, the running pedestrian is more likely to maintain their moving direction than the walking pedestrian. For the case that occurred in the three different areas of vehicle front, the walking pedestrians were mainly performing a backward motion, while most running pedestrians were still moving forward.

"Vertical avoidance movement" (5 cases, 4%) In five cases, pedestrians took a vertical "jump" instead of a horizontal avoidance motion after they recognized the threat posed by the approaching vehicle.

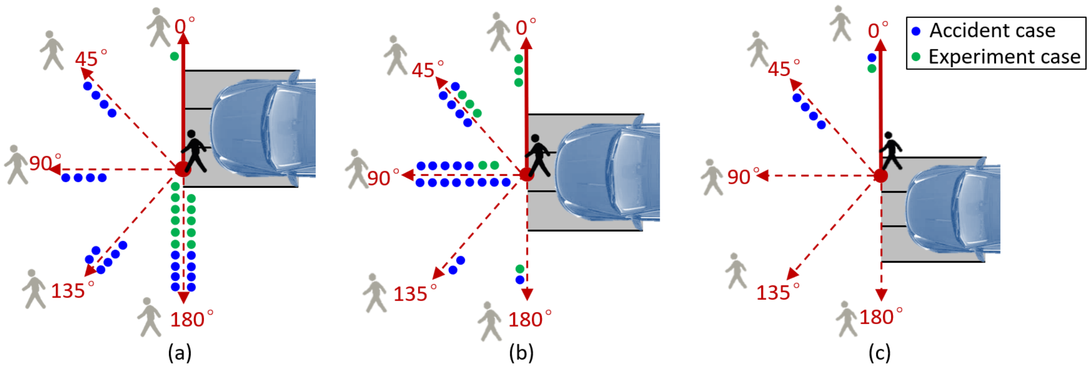

Fig. 3. The direction of the pedestrian avoidance motion in each vehicle front area (each solid blue circle represents one accident case): (a) pedestrian approaching zone, (b) intermediate zone, (c) pedestrian leaving zone.

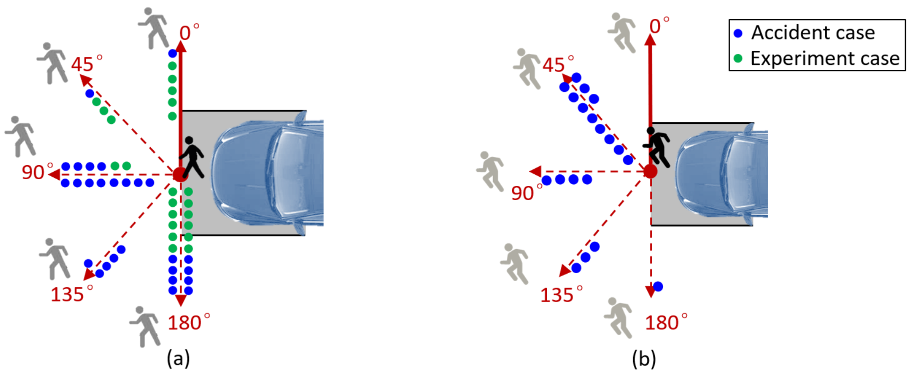

Fig. 4. The direction of the pedestrian avoidance motion in each pedestrian's initial motion state (each solid blue circle represents one accident case): (a) standing or walking, (b) running.

IV. DISCUSSION

Pedestrians remain one of the most vulnerable groups in road traffic environments. Their unpredictable behaviour in emergency situations has had a significant influence on the resultant injury risk and severity, attracting research efforts that use multiple methodologies and/or different data resources. As a preliminary investigation, this study identified the representative avoidance tendencies and the pre-crash whole-body motion of pedestrians using an in-house, self-established video library of real-world car-pedestrian crashes, then comparing the pedestrian motion categories with the results of volunteer experiments. The results show that VR technology can be used to study the natural response behaviour of people in dangerous traffic scenarios while ensuring pedestrian safety. The qualitative analysis of pedestrian kinematics might have significance for improved human modelling as well as for vehicle-pedestrian safety.

According to the accident videos, approximately half of the pedestrians recognized the vehicle's threat and then performed an avoidance motion away from the car, while the other half failed to perceive the danger and kept a normal walking or standing posture. The volunteer experiment results can help to better understand and quantify pedestrian active behaviour characteristics. On the pedestrian side, the natural avoidance behaviour was triggered by the perception of the threat posed by the vehicle. The resultant motion was highly relevant to the pedestrian motion state and the relative location between the pedestrian and the vehicle. For example, for pedestrians located in the pedestrian approaching zone of the vehicle, they mostly exhibited backward step for avoidance; the pedestrians on the pedestrian leaving zone generally moved forward.

On the vehicle side, for a long time the standard and evaluation on pedestrian safety have been limited to a simplified configuration, i.e. pure lateral impact with the pedestrian standing [2][9]. With more diverse scenarios being considered for designing pedestrian-friendly vehicles, the present investigation is anticipated to provide more realistic pedestrian behaviour characteristics for testing and research purposes. The relevant research tools, such as human body models, crash dummies and test scenes, can be expanded to cover the majority of realistic motions.

Several limitations to this study must be noted. The categories were limited to a small sample size and most of the videos were likely uploaded initially not for accident analysis but for other purposes (e.g. visitor volume of a website). Representativeness of our video library was not validated and the degree to which it would affect the established categories needs to be further investigated. The injury analysis for different avoidance categories, which was not presented in this study, will be further investigated in follow-up research. We recognize that substantial claims cannot be made, given the sample size, and are open to adding new motion categories when a wider range of videos are collected and available.

V. ACKNOWLEDGEMENTS

This work was in part supported by the National Natural Science Foundation of China (52072216, 51705276), the State Key Laboratory of Vehicle NVH and Safety Technology (NVHSKL-202105), and the National Key R&D Program of China (2017YFE0118400, 2018YFE0192900).

VI. REFERENCES

[1] WHO, Global Status Report on Road Safety, 2018.
[2] Shang, S., *et al.*, *Saf Sci*, 2020.
[3] Han, Y., *et al.*, *IRCOBI*, 2015.
[4] Tang, J., *et al.*, *SAE Int J Trans Safety*, 2016.
[5] Hu, J., *et al.*, *Int J Vehicle Saf*, 2015.
[6] Kristina, M., Master Thesis, 2017.
[7] Li, Q., *et al., IRCOBI Asia*, 2020 .
[8] Nie, B., *et al.*, *Sci Rep*, 2021.
[9] Nie, B., *et al.*, *Traffic Inj Prev*, 2016.