In vivo Pedestrian Behaviour upon Motor Vehicle Conflicts: Experimental Framework and Initial Results

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I. INTRODUCTION

Pedestrians remains a significant portion, i.e., 26%, of all road traffic deaths given their extreme vulnerability in motor vehicle collisions (MVCs) [1]. The instinctive reactions of pedestrians upon traffic conflicts largely determine the occurrence and severity of accidents [2-3]. Yet, the absence of human-like behaviour in existing research surrogates, e.g., crash dummies, human body models, has limited their potential and application in advanced vehicle safety systems on roads. Up to now, no systematic investigation on such *in vivo* behaviour is available from existing epidemiological, computational, or dummy-based experimental studies [4-5]. This study proposes an experimental framework for extracting typical *vivo* pedestrian behaviour in motor vehicle conflicts. When the volunteers, i.e., pedestrians, entered near-real immersive virtual reality (VR) traffic scenarios. A well-controlled dangerous traffic scene was generated as a visual stimulus to pedestrians. Real-time biomechanical signals of the subjects were recorded during the subsequent natural reactions.

II. METHODS

Subjects

The experimental procedures were approved by the Institutional Review Board (IRB) of Tsinghua University. The procedures were performed in accordance with the approved guidelines. Informed consent from each test subject was obtained before conducting the experiments.

Participating subjects were recruited on campus, Qinghuayuan communities (population about 100,000) through flyer posting physically and online via WeChat Group, i.e., the largest online social platform in China. Subjects had normal (or corrected to normal) vision, hearing, and walking gait, without disability or heart disease. Subjects were selected as a representative of a normal adult, young cohort without gender factors. Thus, we restricted admission to male individuals who were between 18 and 30 years of age. A total of n = 24 subjects conforming to the inclusion criteria volunteered for the study, and data of five subjects were not recorded completely due to technical issues. Data for n = 19 subjects (age range 22.2±1.8 years; height range 1.74±0.04 m; BMI range 21.6±2.3) were completed and finally included in the data analysis.

Experiment platform

The experiment platform was composed of three modules to generate the near-real, immersive VR traffic scene with the parallel measurement of biomechanical signals (Fig. 1.). The in-lab physical area covers about 100 m^2, with the *pedestrian crossing area* representing a 3.5 m-width and 13 m-length zebra crossing rectangular in the VR scene to the subjects (marked in red shadow).

Module I: VR test platform. Consisting of a VR scene generator, a control system, and test devices. The VR traffic scene was designed as a four-lane intersection that was developed by 51VR High Technology Co., LTD. The red border indicates the range that subjects were able to move in, in the VR environment. The test incorporated infrastructure, buildings, trees, traffic light, vehicle, pedestrian, traffic noise, etc. in the VR environment for creating a strong sense of reality. A control system module was designed to control the interaction between the human-in-loop and the implemented traffic objects in the VR scenes, including the appearance position of vehicle and pedestrian, vehicle speed, and traffic signal conversion. Test devices include VR glasses and human posture tracking devices. Subjects entered the VR environment as *pedestrians* by wearing VR glasses and trackers manufactured by HTC Vive (No. VIVE Pro and Wireless adapter). The posture and spatial position of the subjects' body were tracked via motion capture and lighthouse, and were translated into the VR space in real-time.

Module II: Kinetic capture system. Recording the motion information of subjects during the experiment (No. Mars 2H; Beijing Nokov Science & Technology Co., Ltd). This system consists of 12 motion capture cameras (100 Hz),

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54 markers and the relevant software module. 12 cameras were fixed on the edge of the subjects' movement range by tripods (Fig. 1.). Fifty-four markers were attached to the surface of subjects' body through double-sided tape [6].

Module III: Physiological signal system. Electromyogram (EMG) signals of the lower limb muscles of each subject were recorded (16 channels, DELSYS Trigno wireless system). The EMG signal of the left and the right lower limb was measured respectively by eight electrical signal sensors, i.e., measured lower limb muscles included rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM), biceps femoris (BF), gastrocnemius medial head (GMH), gastrocnemius lateral head (GLH), soleus (SO) and tibialis anterior (TA) muscles.

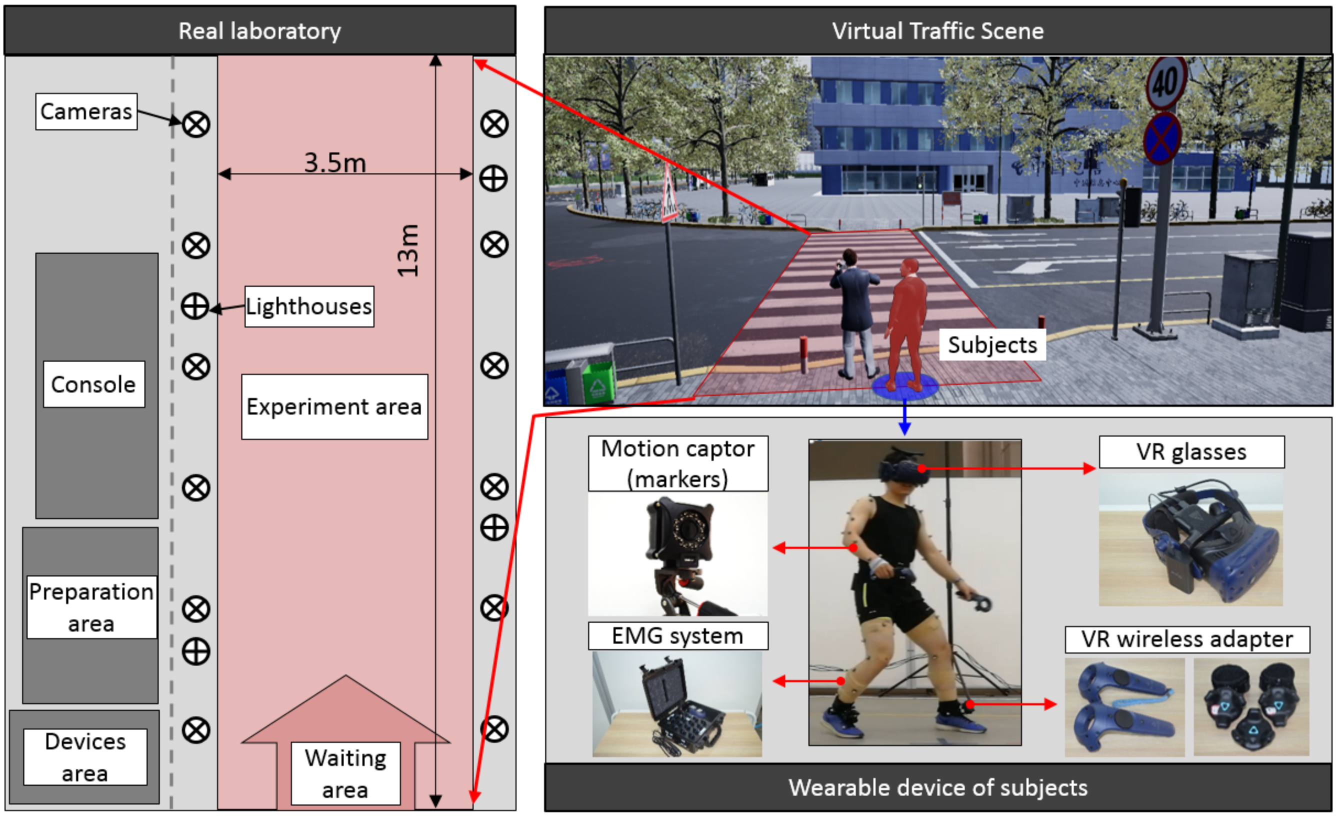

Fig. 1. The overall experiment design

VR Traffic scenes and experiment procedure

Two pre-defined VR traffic scenes were provided to subjects to produce pedestrian-vehicle interaction using the programmed behaviours of a specific *bullet* vehicle (Fig. 2.):

Traffic scene A (TSA): road crossing with a hidden *bullet* vehicle approaching behind visual obstacles (obstacle vehicles);

Traffic scene B (TSB): road crossing with a *bullet* vehicle approaching without visual obstacles.

At the beginning of the experiment, the subjects were told to wait and cross the road when traffic signals on the other side turned green. Regular vehicle flow was provided for a near-real sense. Under TSA, three vehicles would stop in the first lane in front of the subject prior to the signals turning green and deliberately obstruct the subjects' view toward the second lane. An emergent car-pedestrian conflict was produced by the experimenter right after the subject stepped into the middle of the road: a pre-defined bullet vehicle on the second lane had some malfunction, propelling itself forward and resulting in an unintended rushing with a velocity of approximately 60 km/h laterally to the subject.

The synchronously triggered devices would start each device simultaneously for recording whole-body kinematics, posture information (joint angle, joint coordinate, etc.) and physiological sign (EMG) of subjects (*pedestrians*). We programmed the VR devices to save a record of the evolving vehicle parameters, including speed, acceleration, the relative position of the subject (*pedestrian*) and the vehicle.

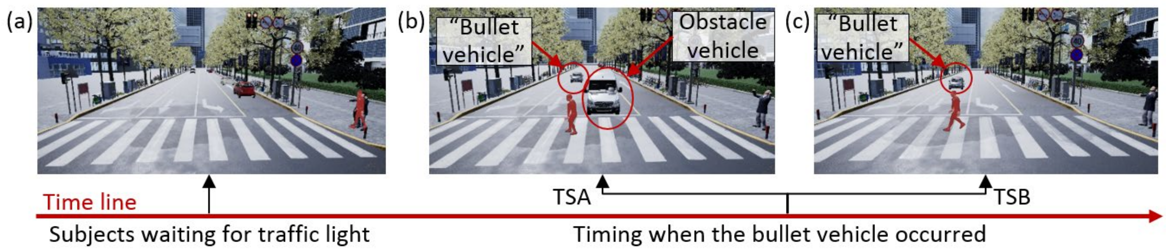

Fig. 2. Representative traffic scenes in the VR environment.

Definition of the pedestrian avoidance behaviour

Reactions of pedestrians in the experiment were categorised depending on their perception of the conflicts and the subsequent motion feature. Overall kinematics were represented by the pelvis motion, including the time histories of the velocity and the acceleration. The *critical posture*, termed as the possible pre-crash posture of the pedestrian, was extracted at the occurrence of the peak value of the pedestrian acceleration during the motion. Such posture indicates momentary posture information during the emergency avoidance process.

III. INITIAL FINDINGS

Representative Reaction Categories in Car-Pedestrian Conflicts

Reactions of participating subjects in the experiment were categorised depending on their perception of the conflicts and the subsequent motion feature (Fig. 3). For the cases in which the pedestrian noticed the approaching vehicle, the avoidance behaviours were categorised into: (1) *backward avoidance* (pedestrians chose to stop and move backwards for avoiding; pedestrians who had not entered the vehicle trajectory only chose to stop) (38%), (2) *forward running* (pedestrians chose to run for avoiding) (21%), (3) *oblique stepping* (pedestrians chose to step away for avoiding) (6%). For the cases in which the pedestrian did not notice the approaching vehicle, the pedestrian behaviour was categorised as (4) *walking* (35%).

For the avoidance behaviour of *backward avoidance* and *forward running*, the pedestrians noticed the approaching vehicle, exhibited collision avoidance capability and sustained significant kinematic and posture change. The stepping behaviour was essentially a startle response, where the pedestrians generally became overwhelmed and were not able to avoid the collision. For the pedestrians who did not notice the approaching vehicle (*walking*), they maintained a normal walking posture and exhibited no avoidance reaction. In such a category, almost all subjects, i.e., 11 of 12, *collided* with the vehicle, i.e., the traffic conflict ended in a car-to-pedestrian collision accident.

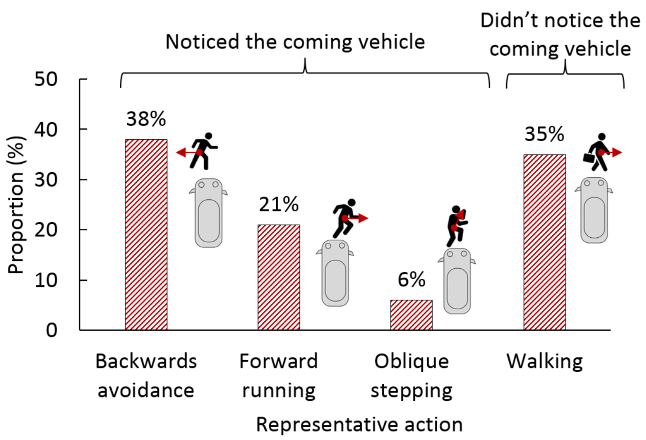

Fig. 3. Reaction categories of the pedestrian in the experiment

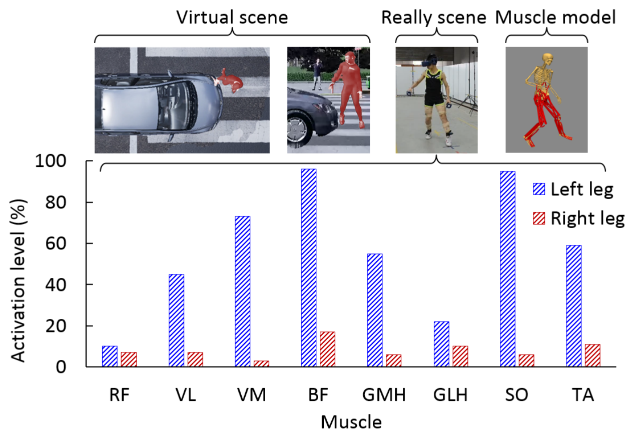

Fig. 5. Normalised muscle active levels at the critical posture (shown: one case in the *backward avoidance* category, the left leg was the supporting leg).

Kinematic Feature of Pedestrian Avoidance Behaviour

The *backward avoidance* behaviour, which involved the pedestrian entering the vehicle's lane, has a two-phase motion: deceleration to stop and a following backward acceleration (Fig. 4a.); the *forward running* exhibited a complete forward accelerating motion (Fig. 4b.). The time of occurrence of peak acceleration was set as a time alignment standard in the phases of backing, backing and running.

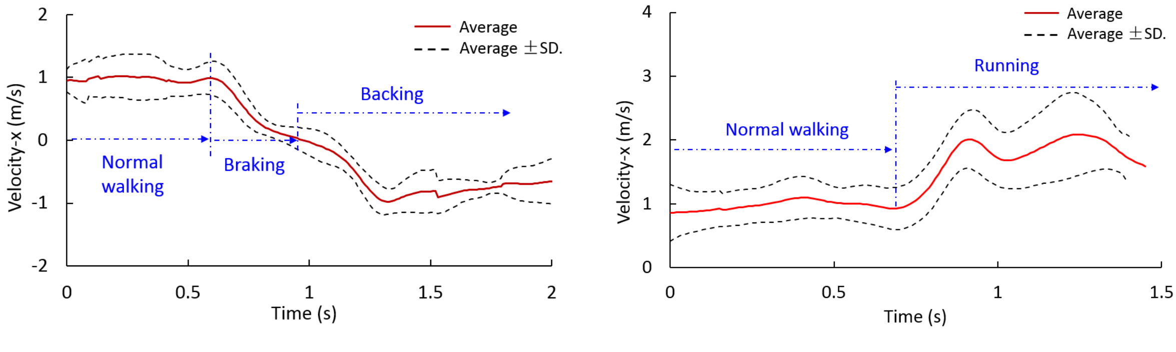

Fig. 4. Kinematic features (velocity corridors) measure at the pelvis of different motion categories: (a) backward avoidance (6 cases), (b) forward running (7 cases). The initial velocity direction of the pedestrians was defined as X-direction.

Active Muscle Responses in the "Critical Posture"

Activations levels of the lower limb muscles in the pedestrian critical posture were identified (Fig. 5). The muscle activation levels of the supporting leg were higher than the unsupported leg, as the supporting leg striked the ground to gain momentum.

IV. DISCUSSION

The human is one key element in the whole human-vehicle-road loop in traffic scenarios. The inherent uncertainties of human behaviour have been posing significant challenges in advanced vehicle safety system design. In parallel, pedestrians exhibited the ability in avoiding danger to a certain level by their own *detection* and *execution* of danger from approaching vehicles. The present experimental framework demonstrates the capability of extracting the isolated human reaction in pedestrian-vehicle conflicts. The generated results are to provide data reference on natural pedestrian behaviour for traffic safety investigation before or during motor vehicle conflicts.

We identified the whole-body kinematics and physiology information of pedestrians in a dangerous traffic environment. The ability of avoiding danger in a pedestrian depends on the timing of the pedestrian perceiving the danger, the relative location, and the moving velocity of the vehicle. For the pedestrians who took emergent reactions, the inherent activation status was explicitly reflected by the activated muscles. These quantitative responses provide a data reference for the development of highly biofidelic research tools, i.e., pedestrian models with active muscles. Overall, the current findings suggest the necessity and potential of fusing active human behaviour in the development of passive and active safety systems especially for vehicles of high automation.

Several limitations shall be noted. The present study demonstrated a recently developed framework but was limited to a specific subject group only, i.e., the young male, and the given traffic scenarios. Other vulnerable pedestrian populations, such as the elderly and the children, sustain high injury risk in vehicle collisions and shall be further considered to quantify the pedestrian-vehicle interactions. As a preliminary investigation on identifying *in vivo* human behaviour, further research efforts are necessary to consider the multi-level variations of the human biology, e.g., eye motion, and the traffic scenario, e.g., vehicle model, collision configurations.

V. ACKNOWLEDGEMENTS

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