Comparison of Human Head Injury Responses Between Western European and Chinese 50th Percentile Subjects in Car-to-Pedestrian Accidents Using Computational Biomechanics Models: Preliminary Results

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I. INTRODUCTION

In 2017, more than 17,000 pedestrians were killed in road traffic accidents in China, and the fatality rate for pedestrians is higher than for other vulnerable road users (VRUs) [1]. Real-world accident reconstruction using computational biomechanics models has been regarded as an efficient approach to investigating how accidents take place and how pedestrian injuries occur [2]. However, the human multi-body (MB) models most commonly used in accident reconstruction, such as the TNO pedestrian models (the Netherlands Organisation for Applied Scientific Research, https://www.tno.nl/en/), are all built based on the Western European anthropometry. Such models are applied in investigation of pedestrian accidents in China without taking into account the anthropometric differences (body mass and stature, geometric proportions and mass distribution of the body segments) between Western European and Chinese populations [3-5]. The objective of this research is to compare pedestrian head injury responses predicted using computational biomechanics MB models representing Western European and Chinese anthropometry.

II. METHODS

Multi-Body Models

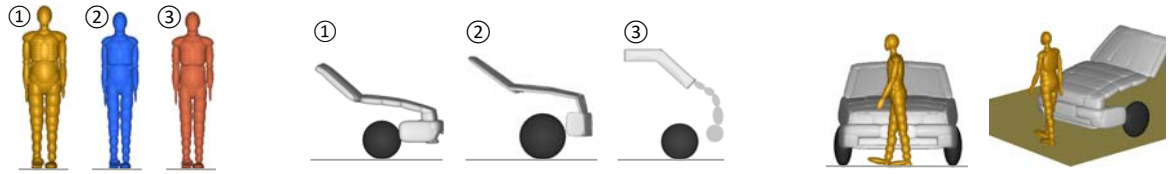
Vehicle safety regulations and safety evaluation programs frequently rely on mechanical (crash test dummies) and computational models representing the 50th percentile male pedestrian/car occupant. Therefore, while acknowledging large anthropometric differences within a given population (see Table 1), in this preliminary investigation we solely focus on MB models representing 50th percentile male pedestrian.

TNO 50th percentile male pedestrian model (referred to as WE-50 model) was modified/"scaled" to represent a Chinese pedestrian. The modification was done in two stages: 1. scaling based on the overall mass and stature of Chinese 50th percentile adult male to build a preliminary pedestrian model (referred to as WE-CN-50 model); 2. further modification according to the proportion/mass distribution of the body segments of Chinese 50th percentile adult male to create complete Chinese 50th percentile pedestrian model (referred to as CN-50 model). These three models (WE-50, WE-CN-50, CN-50) are shown in Fig. 1(a). For detailed information about these models, see Appendix A.

Car-to-Pedestrian Impact Simulation

The WE-50, WE-CN-50 and CN-50 MB pedestrian models were applied in computer simulation of impacts between the pedestrian and sedan, SUV and minivan (see Fig. 1(b)). In the impact, the pedestrian was struck by the vehicle from right-hand side, with the right leg slightly forward, at the impact velocity of 40 km/h (see Fig. 1(c)). In total, we conducted nine simulations: 3 pedestrian models × 3 vehicle front shapes.

We analysed the predicted head injury parameters (head centre of gravity COG linear/angular acceleration and Head Injury Criterion HIC) and head kinematics (head COG trajectory, head impact velocity relative to the vehicle at the head-to-vehicle contact time, and head-to-windscreen impact angle).



(a) (b) (c)

Fig. 1. (a) Three multi-body pedestrian models: ① WE-50 model, ② WE-CN-50 model, ③ CN-50 model. (b) Three typical car front shapes: ① sedan, ② SUV, ③ Minivan. (c) Car-to-pedestrian model impact setup.

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III. RESULTS

The predicted head COG trajectories are shown in Fig. B1. Differences between the results obtained using the models representing Western European and Chinese 50th percentile pedestrians are clearly visible. Fig. 2 shows the kinematics-based head injury responses: head COG linear acceleration, HIC, and angular acceleration. For impacts between the pedestrian and sedan and SUV, the predicted injury parameters for the WE-50 and WE-CN-50 models are lower than for the CN-50 model. For the impacts with minivan, the opposite tendency was observed (the predicted injury parameters for the WE-50 and WE-CN-50 models are higher than for the CN-50 model). Appreciable differences were also observed between the head impact velocity (Fig. 3a and Fig. B2-4) and head impact angle (Fig. 3c) obtained using the CN-50 model and the remaining two models (WE-50 and WE-CN-50), especially for the impact with minivan.

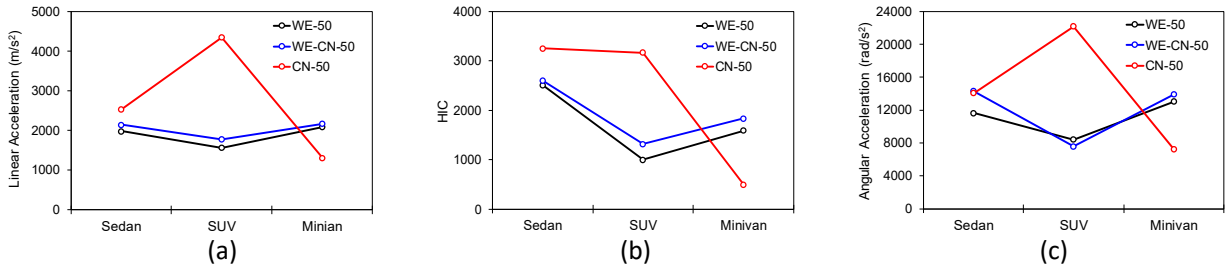

Fig. 2. (a) Head COG linear acceleration, (b) HIC, and (c) Head angular acceleration for three models we used.

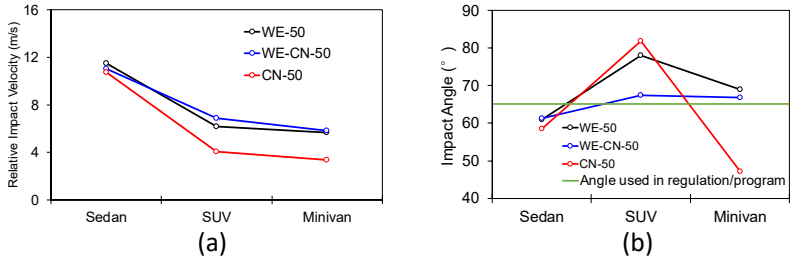

Fig. 3. (a) Head impact velocity and (b) Head impact angle relative to the windscreen/bonnet for three models we used.

IV. DISCUSSION

The head COG trajectories, head injury parameters and boundary conditions for the impact between the pedestrian head and windscreen/bonnet predicted using the CN-50 model (representing 50th Chinese male pedestrian) clearly differ from the results obtained using WE-50 (representing 50th percentile Western European male as defined in [4]) and WE-CN-50 models. These differences are less pronounced in impacts with sedan than with SUV and minivan (Fig. 2 and 3). The results obtained using WE-50 and WE-CN-50 models are close to each other. However, they are appreciably different from results obtained using CN-50 model when modelling impacts between the pedestrian and SUV and minivan. The trend observed in Fig. 2 suggests that for impacts with sedan and SUV, application of a model representing anthropometry of Chinese population can lead to prediction of more severe head injury than for the model built using Western European anthropometric data. The opposite tendency was observed when modelling impacts with minivan. As we focused solely on the population median (we used the models representing a 50th percentile male pedestrian), the results reported here cannot be regarded as a comprehensive evaluation of the effects of anthropometric differences between the Western European and Chinese populations on prediction of pedestrian head injury risk when applying the MB models in pedestrian accident reconstruction in China. However, they seem sufficient to suggest that such differences may need to be considered in Chinese vehicle safety regulations/programs.

V. REFERENCES

[1] Traffic Management Bureau of the Ministry of Public Security PRC, 2017.
[2] Sahoo, D., *et al*., IRCOBI, 2015.
[3] Cao, L., *et al*., *Traf Inj Prev*, 2016.
[4] TNO, MADYMO Human Body Models Manual, Version 7.5, 2013.

[5] Standardization Administration of China, 1988.

VI. **APPENDICES**

A. Differences of the body proportion between Western European and Chinese population.

TABLE I

COMPARISON OF PEDESTRIAN BODY PROPORTION AMONG THE THREE MODELS USED IN THIS STUDY (PLEASE SEE "MULTI-BODY MODELS" FOR DETAILS OF THE MODELS)

No.	Parameter (mm)	WE-50	WE-CN-50	CN-50
1	Standing height	1738	1678	1678
2	Shoulder height	1545	1367	1362
3	Armpit height	1320	1220	1220
4	Waist height	1060	1002	1002
5	Seated height	951	908	891
6	Head length	192	195	195
7	Head breadth	157	153	153
8	Head to chin height	223	223	223
9	Neck circumference	280	360	360
10	Shoulder breadth	461	375	388
11	Chest depth	222	212	220
12	Chest breadth	303	280	299
13	Waist depth	230	195	195
14	Waist breadth	280	273	273
15	Buttock depth	265	211	211
16	Hip breadth, standing	350	306	323
17	Shoulder to elbow length	311	313	311
18	Forearm-hand length	466	420	468
19	Biceps circumference	291	284	284
20	Elbow circumference	278	291	291
21	Forearm circumference	265	261	261
22	Wrist circumference	175	165	165
23	Knee height, seated	562	493	521
24	Thigh circumference	561	522	522
25	Upper leg circumference	513	438	438
26	Knee circumference	438	353	353
27	Calf circumference	372	340	340
28	Ankle circumference	316	208	208
29	Ankle height, outside	91	130	130
30	Foot breadth	95	93	93
31	Foot length	269	256	256
32	Hand breadth	85	85	85
33	Hand length	170	183	182
34	Hand depth	32	26	26

B. Results

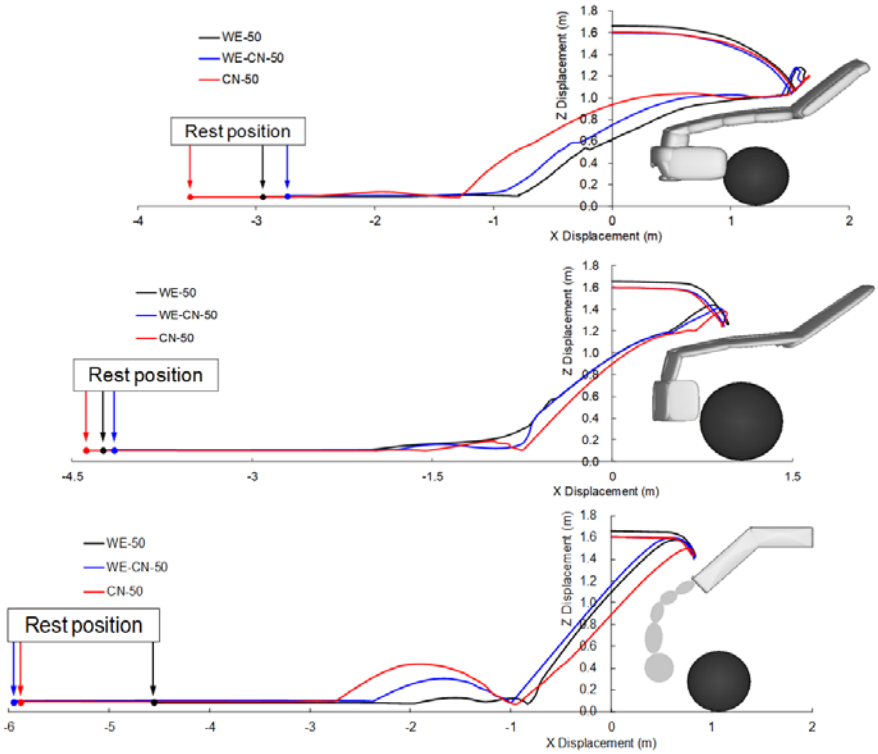

Fig. B1. Trajectory of the head COG predicted for impact with sedan (*top*), SUV (*middle*) and minivan (*bottom*).

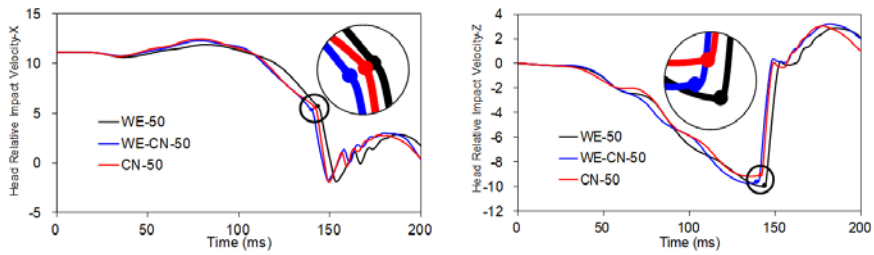

Fig. B2. Predicted time history of head impact velocity relative to the vehicle in direction X (left) and Z (right) in impact with ***sedan*** (The dots in circles denote the values at the head-windscreen contact time).

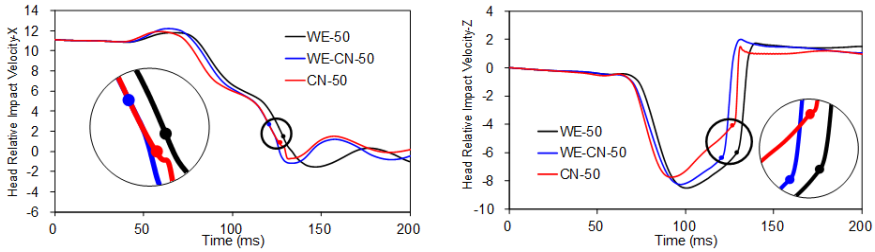

Fig. B3. Predicted time history of head impact velocity relative to the vehicle in direction X (left) and Z (right) in impact with ***SUV*** (The dots in circles denote the values at the head-bonnet contact time).

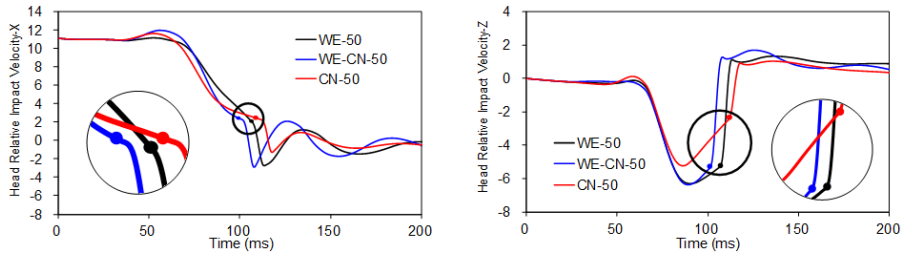

Fig. B4. Predicted time history of head impact velocity relative to the vehicle in direction X (left) and Z (right) in impact with ***minivan*** (The dots in circles denote the values at the head-windscreen contact time).