Comparative study of VRU head impact locations

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Abstract - This study aimed at comparing head Wrap Around Distance (WAD) of Vulnerable Road User (VRU) obtained from the German in-depth Accident Database (GIDAS), the China in-depth Accident Database (CIDAS) and the Japanese in-depth Accident Database (ITARDA micro).
Cumulative distribution of WAD of pedestrian and cyclist were obtained for each database (AIS2+) showing that WAD of cyclists were larger than the ones of pedestrians. Comparing three regions, the 50%tile WAD of GIDAS was larger than that of both Asian accident databases. Using linear regression that might predict WAD of pedestrians and cyclists from *Impact speed* and *VRU height*, WADs were calculated to be 206cm/219cm (Pedestrian/Cyclist) for GIDAS, 170cm/192cm for CIDAS and 211cm/235cm for ITARDA.
In addition, this study may be helpful for reconsideration of WAD measurement alignment between accident reconstruction and test procedures.

INTRODUCTION

Vulnerable Road User (VRU) injuries are a raising concern in the world. Protection against head injuries is offered by softening structures and/or adding protective devices to the areas that are likely to be struck during an impact. The protection offered by a vehicle is assessed in regulatory and consumer testing. Probable impact areas have been investigated using simulation models (e.g. Mottola et al., 2013) and accident data. GIDAS information for example have been used to investigate cyclist and pedestrian head Wrap Around Distance (WAD) information, but results have not been directly comparable to test procedures (see e.g. Zander et al., 2013). Information from accident data on WAD from other regions are sparse. This study aimed at establishing cyclist and pedestrian head WAD information that are directly comparable to test procedures. Furthermore, it was analyzed whether differences between pedestrians and cyclist for head impact locations exist and whether regional influences are observable.

METHODS

Kinematics in pedestrian and bicycle accidents and comparison of WAD type 1 and type 2

At first, it is necessary to explain the kinematics during a car to pedestrian and a car to bicycle accident. In the next step it is essential to define the different measurement of WAD type 1 and type 2. Therefore the different measurement types are explained with an example of a car to pedestrian accident. The pedestrian kinematics in a car to pedestrian accident is in general divided into four different phases

- **Contact phase**

  This phase begins with the first contact between car and pedestrian and ends in the situation when the pedestrian has approximately adopted the vehicle speed or if there is a separation between car and pedestrian. This phase can be subdivided into two phases:
  - First contact with leg and hip (1. Acceleration, Fig.1)
  - Scoop up, impact of torso and head (2. acceleration) and maybe the following transport range (Fig.2)
- **Transport phase**

  If the car is not decelerating after the collision, it is possible (dependent on car type and design) that the pedestrian is transported on the engine hood or the roof of the car until the car is decelerating or the pedestrian falls of the car because of gravitation (Fig.3).

- **Flight phase**
  This phase begins with the separation of the pedestrian and ends with the impact of the pedestrian on or next to the driving lane. A vehicle contact of a single body part is also possible during flight.
- **Slip phase**
  This phase begins with the impact on or next to the driving lane and ends with the final position of the pedestrian.

In this study only the contact phase of the pedestrian until the head impact was important for measuring the wrap around distance. The different measuring methods of WAD type 1 and type 2 are explained in the next step.

Figure 1. Kinematics of pedestrian; Contact phase (First contact)

Figure 2. Kinematics of pedestrian; Contact phase (Scoop up)

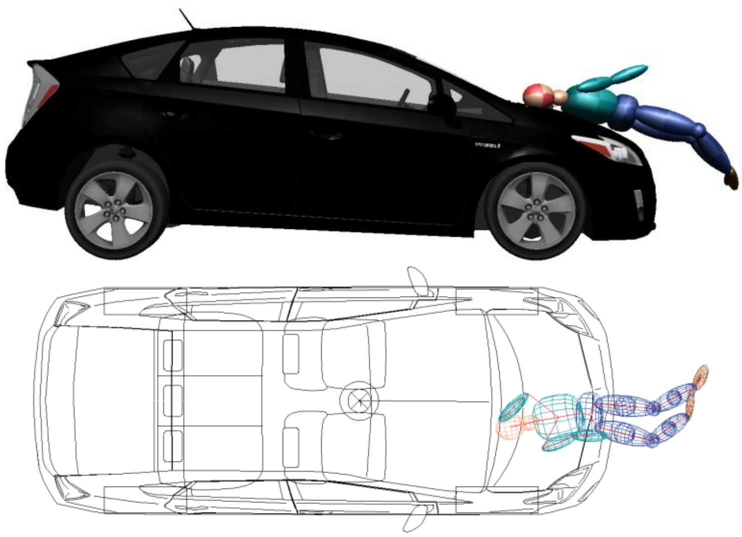

Figure 3. Kinematics of pedestrian; Transport phase

We suppose that the first impact of the right leg against the car front bumper has left a trace on the front bumper (scratch, dent) and the head impact has caused a dent in the engine hood. This traces are marked in the 3d-view of the car (Fig.4).

The distance in y-direction (lateral axis of the car) of the two dents is called **offset of the dents**. The measuring is always done from the middle of the dents or traces. In a perpendicular accident, the offset of the dents is only dependent on the movement speed of the pedestrian not on the speed of the car.
The distance in x-direction (longitudinal axis of the car) from the front of the car to the middle of the head impact dent is called **throw up distance**. The throw up distance depends on the movement speed of the car, the design of the cars front, body size and body weight of the pedestrian.

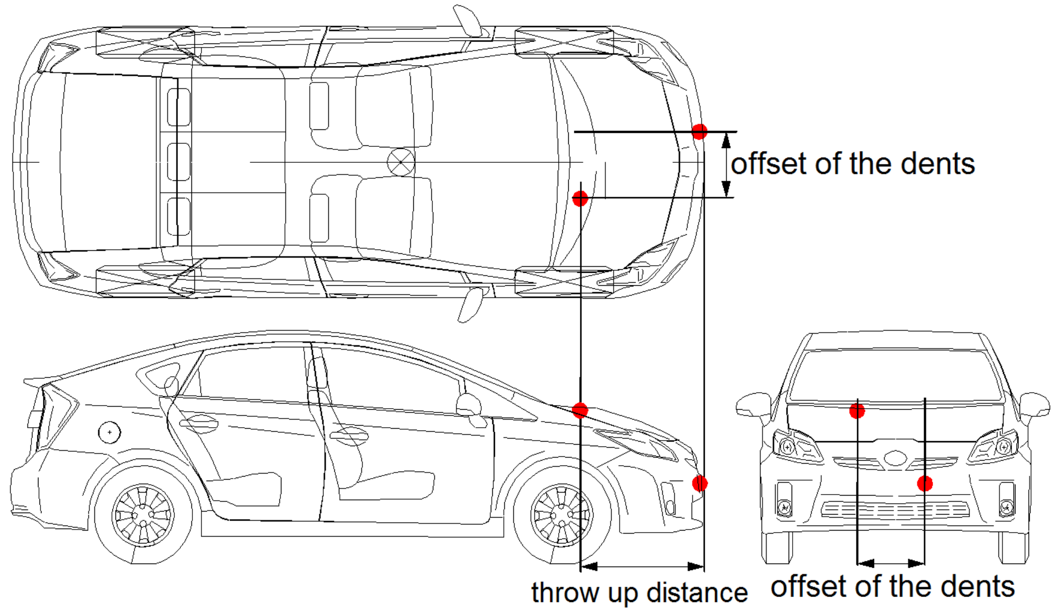

Figure 4. “offset of the dents” and “throw up distance”

The measuring of WAD is done with a measuring tape orthogonal under the first contact point of the vehicle front to the middle of the head impact point. The measuring of the WAD type 1 is done only in x-direction, thus along the lateral axis of the car (Fig.5) whereas the measuring of WAD type 2 is done in x-direction and in y-direction (Fig.6).

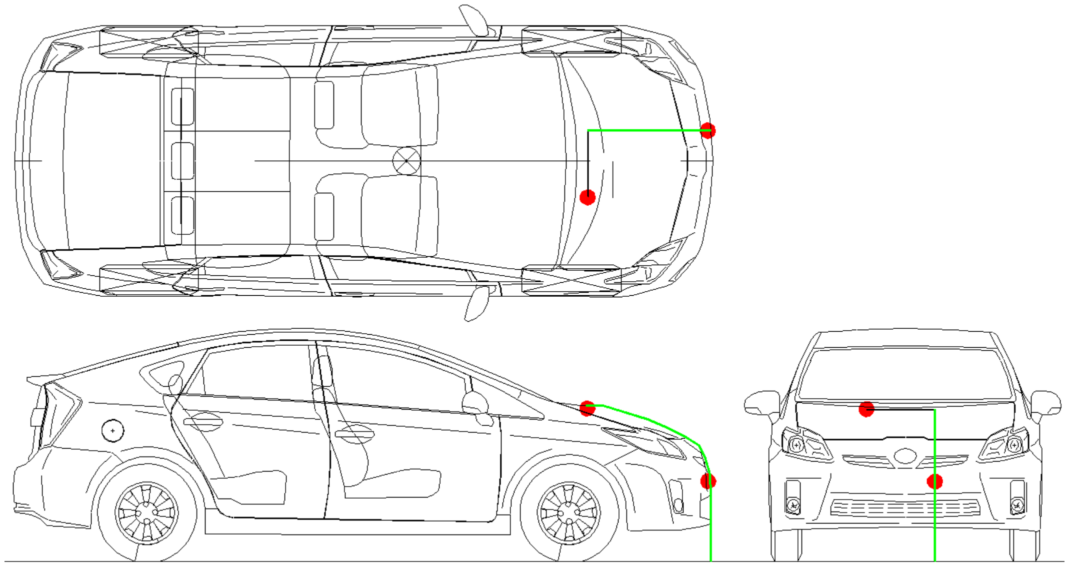

Figure 5. Measuring of WAD type 1

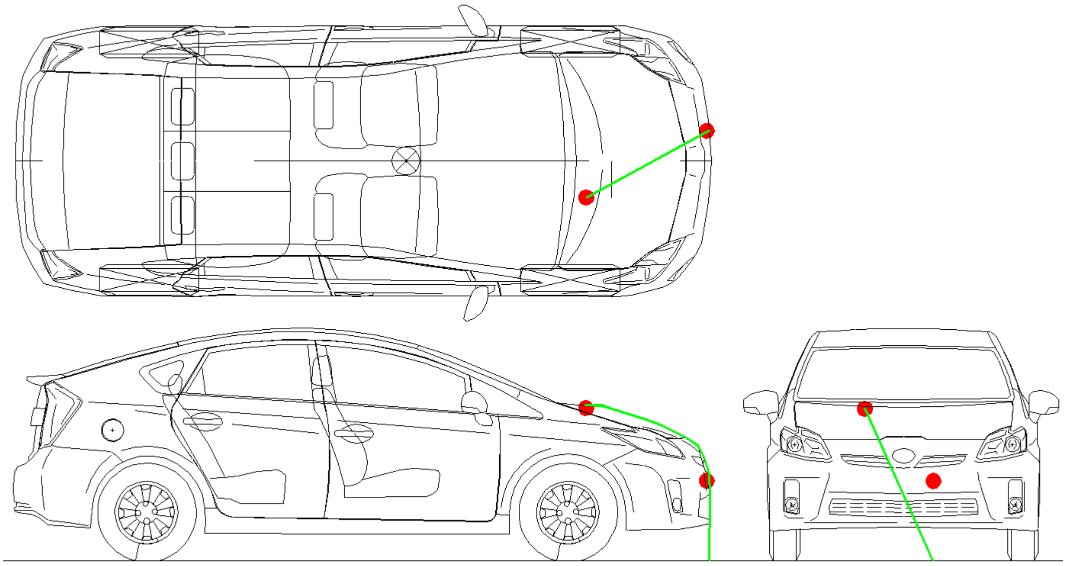

Figure 6. Measuring of WAD type 2

If there is no offset of the first contact at the front of the car and the head impact, the measurements of WAD type 1 and type 2 will show no difference. If there is an offset of the first contact at the front of the car and the head impact, the measurements of WAD type 1 and type 2 will show different results. Measuring with WAD type 2 will show larger wrap around distances than measuring with WAD type 1, because in the WAD type 2 a part of the offset of the first contact at the front of the car and the head impact is included.

Dependency of WAD on different parameters

As representative in-depth-accident study, GIDAS was used for finding frequencies of vehicle involvement. Accidents of the years 1999 to 2013 were analysed with focus on WAD.
GIDAS, CIDAS and ITARDA (micro) accident databases are used to extract head WAD for pedestrian and cyclists. For GIDAS, a case-by-case analysis was conducted to ensure the WAD information is directly comparable to test procedures, i.e. measured along the vehicle’s longitudinal axis (type 1). For CIDAS and ITARDA (micro), WAD information is always measured along the vehicle’s longitudinal axis (type 1), thus case-by-case analysis was not required.
Head impact WADs were plotted as empirical cumulative distributions with 95% confidence intervals using MATLAB R2013a. Differences between pedestrians and cyclists on the one hand and between the countries on the other hand were given. For each country, multivariate linear regressions were defined to explain WAD as an outcome of pedestrian height and vehicle speed.

RESULTS

Cumulative distributions of WAD for each database atAIS2+ injury level are shown in Fig.7, 8 and 9, respectively. In each country, WAD of cyclists was larger than that of pedestrians. Among the three accident regions, the 50 percentile WAD of GIDAS was largest.

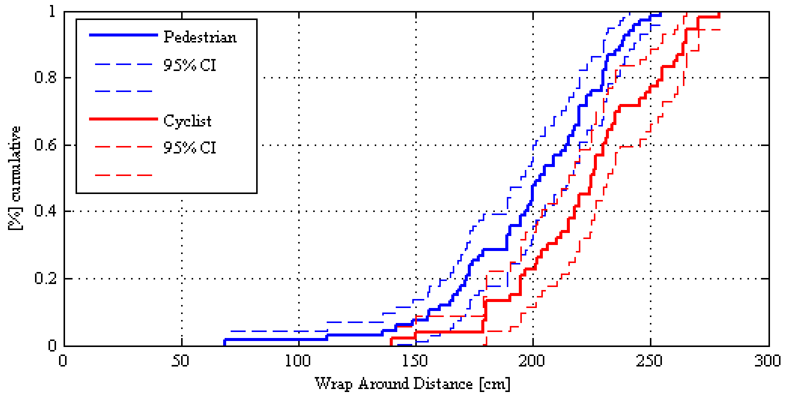

Figure 7. Cumulative distribution of Wrap Around Distance from GIDAS (AIS2+)

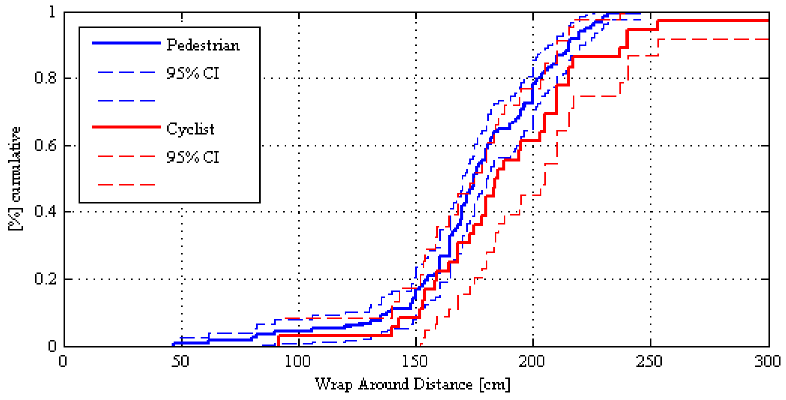

Figure 8. Cumulative distribution of Wrap Around Distance from CIDAS (AIS2+)

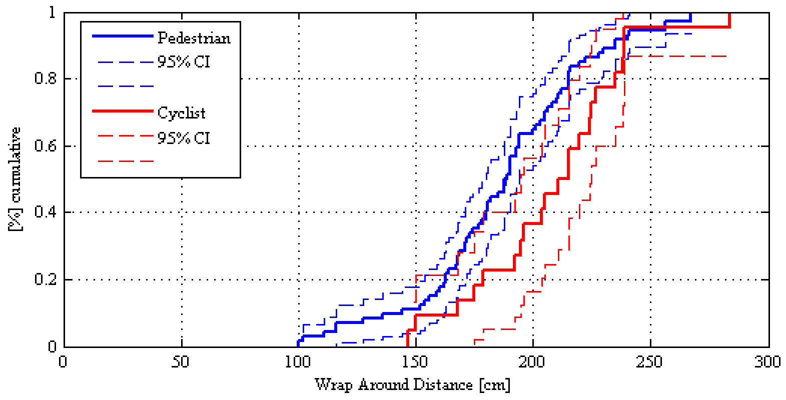

Figure 9. Cumulative distribution of Wrap Around Distance from ITARDA (AIS2+)

Linear regressions predicting WAD (cm)based on VRU height (cm) are shown in Fig.10, 11 and 12, respectively. Mean VRU heights and full model specifications of the three accident regions are given in table 1. Sample size (n), R^2 values and p-values for each predictor are given to indicate overall model fit. In Japan, the smallest mean VRU heights were observed.

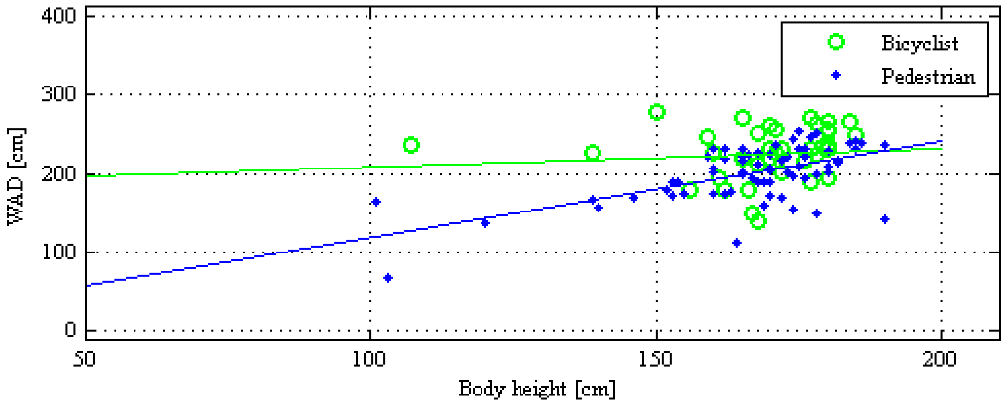

Figure 10. Linear regression WAD=f(VRU height) for GIDAS (AIS2+)

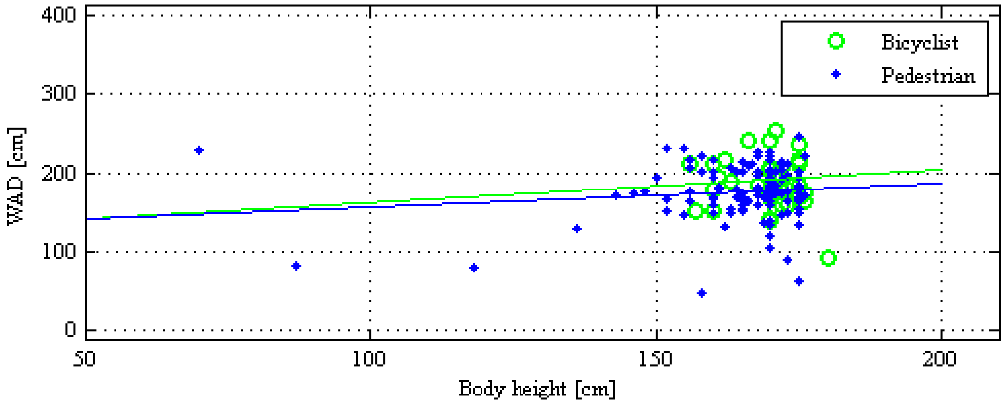

Figure 11. Linear regression WAD=f(VRU height) for CIDAS (AIS2+)

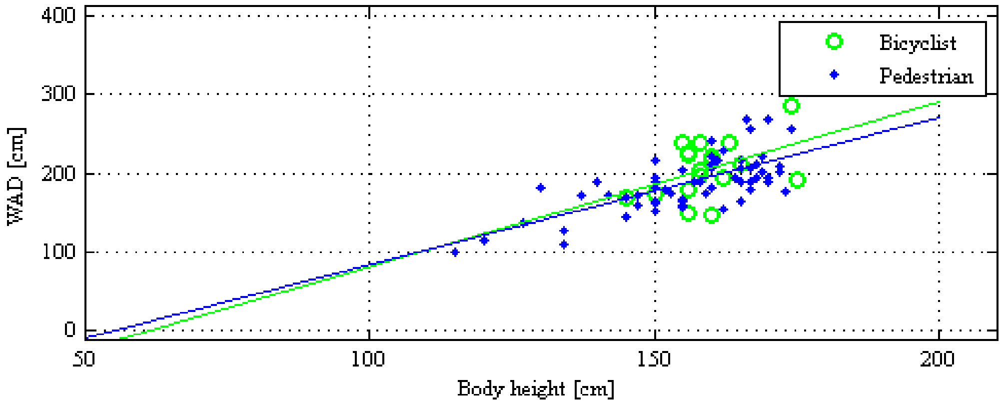

Figure 12. Linear regression WAD=f(VRU height) for ITARDA (AIS2+)

Table 1: VRU height description and model specification for linear regression WAD=f(VRU height)

		VRU height		Intercept			VRU height				
		mean	SD	value	SE	p	value	SE	p	n	R^2
GIDAS	Ped	166	16.7	-2.53	34.5	0.94	1.21	0.21	<0.01	67	0.35
	Cyc	169	13.2	185.8	66.8	<0.01	0.23	0.39	0.56	39	<0.01
CIDAS	Ped	163	17.1	125.5	36.1	<0.01	0.30	0.22	0.17	118	0.02
	Cyc	167	14.4	120.6	190	0.53	0.41	1.12	0.72	36	<0.01
ITARDA	Ped	156	13.3	-102.3	38.7	0.01	1.86	0.25	<0.01	60	0.49
	Cyc	161	8.0	-127.4	174	0.47	2.09	1.09	0.07	18	0.19

Linear regressions predicting WAD (cm) based on impact speed (km/h) are shown in Fig.13, 14 and 15. Mean impact speeds and full model specifications of three regions are given in table 2

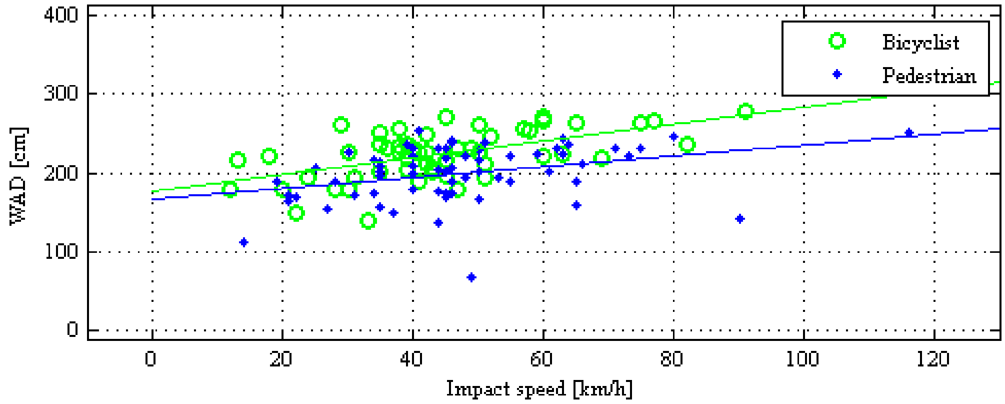

Figure 13. Linear regression WAD=f(impact speed) for GIDAS (AIS2+)

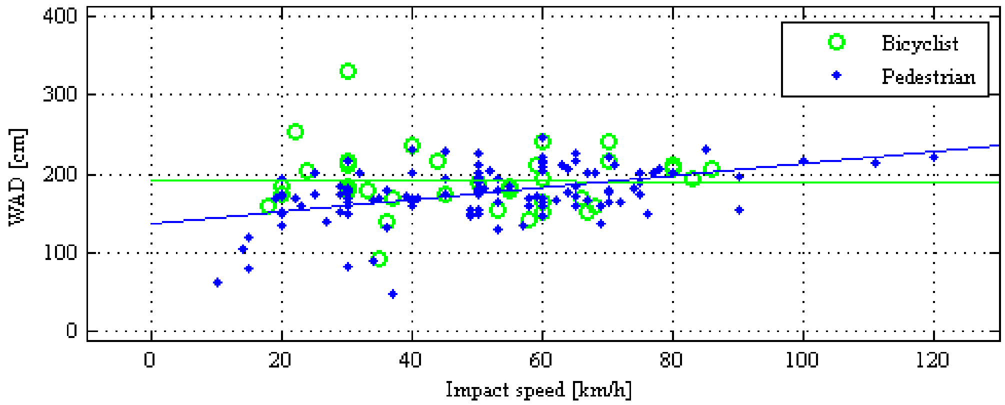

Figure 14. Linear regression WAD=f(impact speed) for CIDAS (AIS2+)

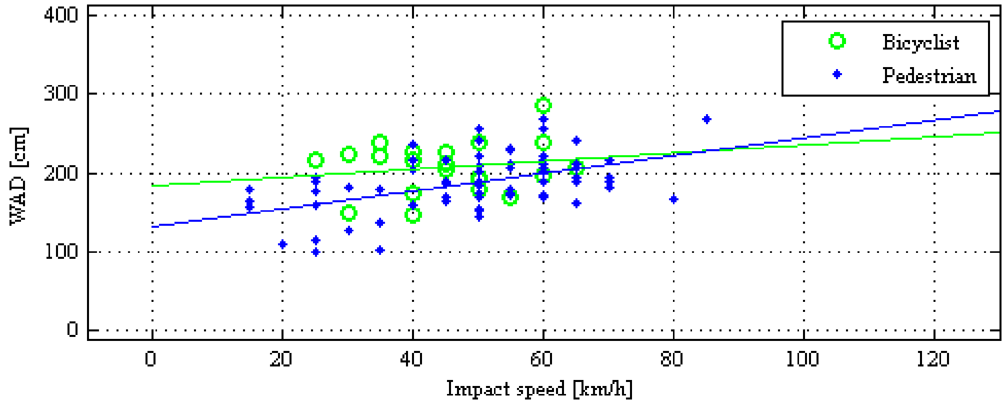

Figure 15. Linear regression WAD=f(impact speed) for ITARDA (AIS2+)

Table 2: Impact speed description and model specification for linear regression WAD=f(speed)

		Impact speed		Intercept			Impact speed				
		mean	SD	value	SE	p	value	SE	p	n	R^2
GIDAS	Ped	47	17.4	167.7	11.7	<0.01	0.67	0.23	<0.01	66	0.11
	Cyc	49	17.5	175.9	10.2	<0.01	1.07	0.22	<0.01	53	0.32
CIDAS	Ped	44	23.8	137.3	7.3	<0.01	0.75	0.13	<0.01	119	0.21
	Cyc	38	19.9	192	18.5	<0.01	-0.03	0.35	0.93	36	<0.01
ITARDA	Ped	49	16.0	132.4	12.1	<0.01	1.12	0.24	<0.01	72	0.24
	Cyc	44	12.4	184.1	30.9	<0.01	0.51	0.66	0.45	21	0.03

Table 3 displays model specifications for linear regression that predicts WAD of pedestrian and cyclists (in cm) using impact speed (km/h) and VRU height (cm) simultaneously.

Table 3: Model specification for linear regression WAD=f(impact speed,VRU height)

		Intercept			Impact speed			VRU height				
		value	SE	p	value	SE	p	value	SE	p	n	R^2
GIDAS	Ped	-1.7	34	0.96	0.35	0.21	0.09	1.11	0.21	<0.01	66	0.38
	Cyc	172	54	<0.01	1.14	0.25	<0.01	0.01	0.32	0.97	39	0.37
CIDAS	Ped	105	32	<0.01	0.74	0.13	<0.01	0.20	0.20	0.32	118	0.22
	Cyc	114	220	0.61	0.03	0.39	0.95	0.44	1.25	0.36	36	<0.01
ITARDA	Ped	-93	36	0.01	0.68	0.20	<0.01	1.58	0.24	<0.01	58	0.59
	Cyc	-135	178	0.46	0.49	0.74	0.52	2.0	1.12	0.09	18	0.21

Using these linear regressions, VRU WADs (in cm) are predicted under the condition that a VRU height is 175 cm and an Impact speed is 40 km/h. Table 4 gives predicted WADs.

Table 4: Predicted WAD for a VRU of 175 cm and an impact speed of 40 km/h

	GIDAS	**CIDAS**	**ITARDA**
Pedestrian	206	170	211
Cyclist	219	192	235

ITARDA has the largest predicted WAD for both Pedestrian and Cyclist at these conditions, but differences to GIDAS are small with less than 20 cm. CIDAS predicted WAD is by far the shortest.

DISCUSSION

The results of this study can guide the definition of a probable head impact area and in turn aid the development of protective devices and test procedures.

The results are based on retrospective accident data, which under samples non-injury cases and might be prone to measurement error. Partly small sample sizes in the linear regression models and less-than-ideal model fit needs to be taken into consideration when interpreting results. Thus, the findings of this study should be supplemented using simulation methods. Edwards et al. (2014) give a simulation based prediction of pedestrian head WAD in the form WAD = -2227 + 335 * log(impact speed) + 1.8 * Pedestrian height. WAD and height are measured in mm, impact speed in km/h.

For the impact condition in table 4, 216cm WAD are predicted, which is 5 to 10 cm larger than results from ITARDS and GIDAS, respectively.

Fredriksson and Rosén (2012) used GIDAS AIS3+ data to calculate an equation WAD = -28 + 0.49 * Impact speed + 1.2 * Pedestrian height, where WAD and height are given in cm, impact speed in km/h. For the impact condition in table 4, 201 cm WAD is predicted, which is comparable to our study.

CONCLUSION

- Head impact WAD for pedestrians and cyclists in Germany, China and Japan are established in a manner that is directly comparable to test procedures. Influential factors VRU height and impact speed that determine WAD are quantified.

- For each of the three countries, WAD is predicted using VRU height and impact speed. These predictions might indicate areas relevant for VRU impact protection.

- Lastly, this study may be helpful for reconsideration of WAD alignment between accident reconstruction and test procedures.

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