

# POTENTIAL INFLUENCE OF THE FRONTEND GEOMETRY OF PASSENGER CARS ON TRAJECTORIES AND INJURY SEVERITIES IN PEDESTRIAN CRASHES

**Oliver Zander, Tobias Langner**

Federal Highway and Transport Research Institute (BAST)  
Germany

Paper Number 26-113

## ABSTRACT

The evaluation of passive safety for passenger car frontends during crashes with vulnerable road users relies on pedestrian impactor tests (head: accelerations; pelvis: sum of forces; lower extremities: femur/tibia bending moments, knee ligament elongations) as defined in current consumer programmes and legislation. The obtained readings mainly reflect vehicle stiffness and deformation space for energy reduction, while frontend geometry is largely disregarded.

Different data sources suggest correlations between frontend parameters and pedestrian injury frequency and severity. This study investigates the potential influence of passenger car frontend geometry on pedestrian impact kinematics and injury severity using full-scale vehicle-to-dummy tests:

Four tests with two vehicle categories (Sedan and small SUV) against the “Primus Unbreakable” dummy were performed at different speeds and dummy orientations at BAST. Dummy trajectories were compared, and vehicle contact points for head, chest, pelvis, and knee were recorded. Loadings to head, chest, and pelvis were measured and analyzed.

Results reveal some significant differences in impact kinematics and dummy trajectories. For example, the small SUV’s higher, blunter frontend pulls lower extremities underneath, delaying wrap-around. The pelvis strikes the presumably stiff bonnet leading edge, and the dummy’s trajectory is higher than with the Sedan, with the head impacting further forward. These observations indicate potentially higher injury severity, particularly for head, pelvis and lower extremities, although further investigations are required, considering material properties and available actual deformation space.

Comparing head, chest, and pelvis accelerations at equal speeds shows higher chest and pelvis values for the small SUV, suggesting higher injury potential for these regions; head results remain inconclusive.

High head readings must be contextualized, as dummy structure differs from crash test dummies or PMHS tests. Chest and pelvis accelerations aren’t used as injury criteria.

This investigation provides initial insights into complementing current vulnerable road user safety assessments with a geometry factor in the future.

**Keywords:** Passive safety of pedestrians and bicyclists, geometry-based vehicle safety assessment, impactor tests, full-scale dummy tests, impact kinematics, trajectories.

## INTRODUCTION

In 2024, a total of 402 pedestrians were fatally injured and 4,950 sustained severe injuries on German roads. Consequently, pedestrians accounted for 14.5% of all road traffic fatalities and 9.8% of all individuals with severe injuries among road users. In this context, collisions involving passenger cars play a particularly significant role. Specifically, 218 pedestrians were killed during collisions with exactly one passenger car, and 3,326 pedestrians suffered severe injuries [1]. Focus of passive vehicle safety is mitigating the injuries suffered during road collisions. To assess the protection of vulnerable road users, motor vehicles of categories M1 and N1 derived from M1 (Global Technical Regulation No. 9 (GTR9) [2]: vehicle categories 1-1 with GVM > 500 kg, 1-2 and 2 with 500 kg < GVM ≤ 4.5 t) are subjected to component tests in accordance with European type approval procedures [3][4]. Under standardized boundary conditions, the vehicle front structures undergo controlled tests with impactors that represent specific pedestrian body regions. The recorded biomechanical response parameters are compared with established injury risk thresholds derived from accident epidemiology and biomechanical research. This comparison provides the basis for assessing the vehicle's injury mitigation potential and overall pedestrian safety performance in vehicle to pedestrian collisions. The evaluations serve two primary purposes: (1) compliance verification with regulatory minimum requirements e.g. for type approval, (2) provision of input data for consumer safety rating systems such as the European New Car Assessment Programme (Euro NCAP) [5], which apply more stringent protocols and scoring methodologies beyond legal standards.

Current pedestrian component tests predominantly address the assessment of material stiffnesses of the vehicle frontend based on accelerations, forces, elongations and bending moments during the impact. Despite of parameters such as bonnet angle and bonnet leading edge (BLE) height exerting a certain influence on relative impact angles and impact energies, critical geometric characteristics of the front-end design - such as bumper height and bumper lead, BLE height, bumper lead angle, bonnet and windscreen angle, overall vehicle width - are largely neglected. These factors, however, play a decisive role in pedestrian kinematics and the determination of relevant impact conditions.

Full-scale vehicle tests with full-body dummies are generally well-suited to address specific questions regarding the influence of frontend geometry on pedestrian impact kinematics. To investigate these aspects, a series of vehicle tests against the the biofidelic dummy "Primus Unbreakable" [6] was performed at BAST. This dummy is expected to replicate the trajectories of and loadings to vulnerable road users (VRU) observed during real-world pedestrian crashes at the expense of limited repeatability and reproducibility.

## CURRENT STATUS

Current VRU test and assessment procedures in consumer information programmes (Euro NCAP) and legislation (UN Regulation No. 127) evaluate the passive protection potential of vehicle frontends in car-to-VRU collisions based on measurement results (head: accelerations; pelvis: maximum sum of forces; lower extremities: bending moments in femur and tibia, ligament elongations in the knee) from component tests with pedestrian impactors representing different body parts or regions. The measured forces, moments and elongations primarily provide insights into vehicle stiffness and the available clearance for dissipating impact energies. However, the vehicle frontend geometries remain largely unconsidered. In a study conducted by the U.S. Insurance Institute for Highway Safety (IIHS), the U.S. vehicle fleet was classified into six categories according to frontend geometric characteristics (blunt or sloped bumper leads combined with high, medium and low bonnet leading edges). In-depth crash analyses revealed correlations between frontend geometry and the frequency and severity of injuries. In summary, vehicles with higher and blunter front ends were associated with, on average, more severe injuries [7]. In particular, a combination of higher and blunter vehicle frontends was more frequently associated with torso and hip injuries, with higher injury severities. Moreover, the likelihood of a pedestrian rebounding and being propelled forward after an impact with high and blunt vehicles was two to three times greater compared to other vehicle types. Overall, the referenced study assigns considerable importance to vehicle frontend geometry, suggesting a potential key role in the frequency and severity of pedestrian injuries in such collisions.

## METHODS

To gain a more detailed insight into the influence of geometry parameters of vehicle frontends on pedestrian kinematics and injury severities during crashes, four full-scale vehicle tests with Sedan and small SUV representative against a pedestrian surrogate that were carried out at the crash test facility of BAST were further investigated. Details with regards to test preparation, execution and evaluation can be found in ESV paper 26-112 [8]. As pedestrian surrogate the “Primus Unbreakable” 50th percentile male biofidelic dummy [6] was used:

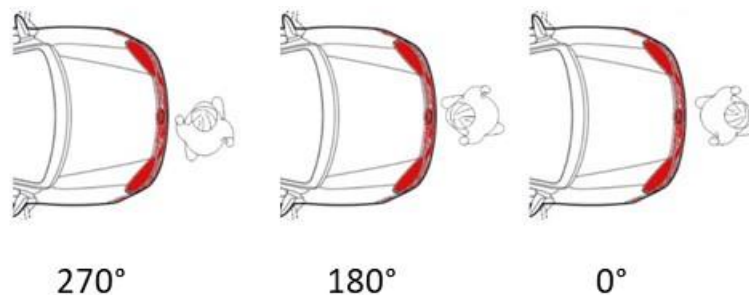


*Figure 1. 50th percentile biofidelic dummy „Primus Unbreakable“.*

The „Primus Unbreakable“ was equipped with sensors to capture linear head accelerations, angular velocities, and chest and pelvic accelerations in three dimensions. Test scenarios were reconstructed using two vehicle types representative of European best-selling models: a Sedan and a small SUV. Three Sedan tests simulated accident types 671/674 (longitudinal scenario, same direction), 672/673 (longitudinal scenario, opposing direction) and 421 (pedestrian crossing from near-side) as defined in [9], varying dummy position and orientation, with impact speeds of 40 km/h. The test with the small SUV simulated accident type 421, see Table 1 and Figure 2:

*Table 1.  
Overview of full-scale vehicle to dummy tests*

Vehicle	Test No.	Accident Type	Vehicle Speed	Dummy orientation
Sedan	BFUPGL1	421 – crossing near-side	40 km/h	270° - y0
Small SUV	BFUPTL1	421 – crossing near-side	40 km/h	270° - y0
Sedan	BFUPGF1	672/673 – long., opp. dir.	40 km/h	180° - y0
Sedan	BFUPGR1	671/674 – long., same dir.	40 km/h	0° - y0



*Figure 2. Dummy orientation during full-scale vehicle tests.*

In all cases, the dummy was struck at the vehicle’s foremost end at vertical longitudinal centreplane. The dummy was positioned to mimic forward walking motion, with weight distribution primarily on the right leg. Due to the absence of muscle tension, an electromagnetic suspension system was employed to maintain upright posture until the time of impact, released immediately prior to collision. For the reconstruction of impact points on the vehicle, the dummy was marked with dots of different colours (head: red – chest: yellow – pelvis: green – knees: blue).

Based on the crash tests conducted with the Primus dummy, an initial verification of the potential effects of the front-end geometry on pedestrian impact kinematics and the resulting injury severities was carried out. For this purpose, the two test vehicles were classified according to the IIHS vehicle categorization [7], compare Table 2 and Figure 3:

**Table 2.**  
*Vehicle categorization according to IIHS method (bold: small SUV and Sedan used in the crash tests)*

Bumper lead angle	$> 65^\circ$	$\leq 65^\circ$
BLE height		
<b>BLE &gt; 40"</b>	tall, blunt	tall, sloped
<b>40" <math>\leq</math> BLE &lt; 30"</b>	<b>medium, blunt</b>	medium, sloped
<b>BLE <math>\leq</math> 30"</b>	low, blunt	<b>low, sloped</b>



**Figure 3.** *Vehicle measurement and categorization according to IHRA method, example SUV.*

Based on the vehicle categorization in Table 2, the Sedan used in this study represents a low-profile vehicle with an inclined front structure, whereas the small SUV representative exhibits a mid-height, blunt frontal design. These morphological differences are expected to influence pedestrian kinematics as well as the injury frequency and severity in pedestrian crashes involving these vehicles [7]. Specifically, blunt vehicle fronts have been associated with increased injury severity, particularly in the pelvis region, but also for the torso and head, compared to sloped front profiles.

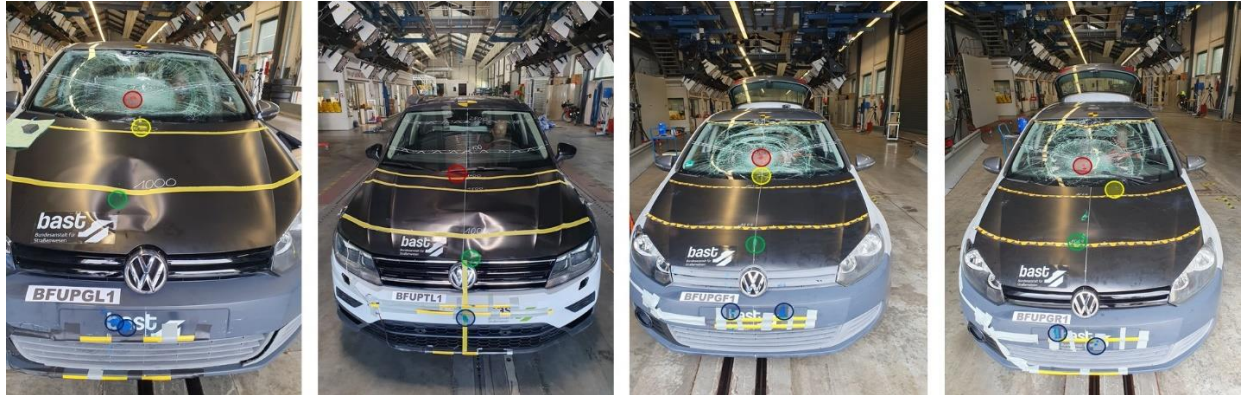
## RESULTS

Initially, the dataset was derived from two lateral crash tests involving both, Sedan as well as small SUV representative, conducted against the Primus dummy at constant vehicle speed of 40 km/h. In both tests, the dummy crossed the roadway from near side (right to left from the driver’s perspective), with the point of first contact on the vehicle’s longitudinal vertical centreplane. Supplementary, in a second step, a comparative analysis was performed between two additional impact configurations using the Sedan, in which the dummy was oriented either facing towards

or away from the vehicle. In these tests, the vehicle speed remained at 40 km/h with collision at longitudinal vertical centreplane.

**Contact locations**

Following the completion of the tests, the color markings previously applied to the head, chest, pelvis, and knees enabled an approximate determination of their respective contact points on the vehicle. The vehicle contact locations for all tests are presented in Figure 4 - please note that the chest contact during the test with small SUV was on the inner side of the upper arm.



**Figure 4. Vehicle contact locations of Primus Unbreakable (head: red – chest: yellow – pelvis: green – knees: blue). Scenarios from left to right: Sedan (crossing near side), small SUV (crossing near side), Sedan (longitudinal opposing direction), Sedan (longitudinal same direction).**

Furthermore, the throw distances of the dummy, including its final positions, was recorded.

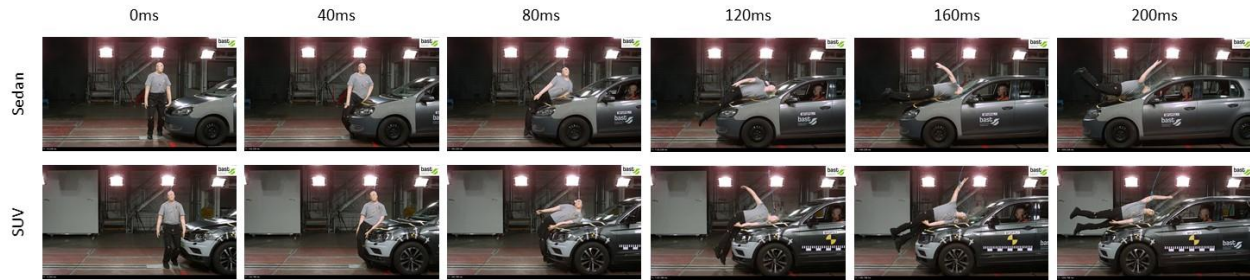
An overview of all contact zones and throw distances is provided in Table 3:

**Table 3.**  
*Vehicle contact locations, throw distances and final dummy positions*

<b>Post Test Sedan / small SUV</b>				
	<b>BFUPGL1</b>	<b>BFUPTL1</b>	<b>BFUPGF1</b>	<b>BFUPGR1</b>
<b>WAD Head</b>	2010	1760-1810	2098	1970
<b>WAD Chest</b>	1540	n/a	1700	1520
<b>WAD Knee left/right</b>	450	500	400/500	470/440
<b>WAD Thigh / Pelvis</b>	930	850-880	810-990	970-1060
<b>Throw distance Dummy (Crotch / CoG Head) [cm]</b>	n/a	530/445	350/457	530/610

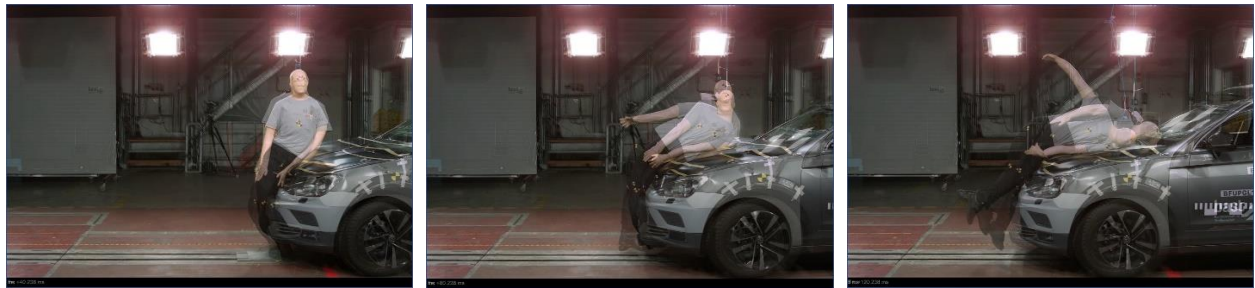
### Timing – lateral impacts

A comparison of the dummy kinematics in both lateral impacts is shown in Figure 5:



*Figure 5. Dummy kinematics during lateral crash tests.*

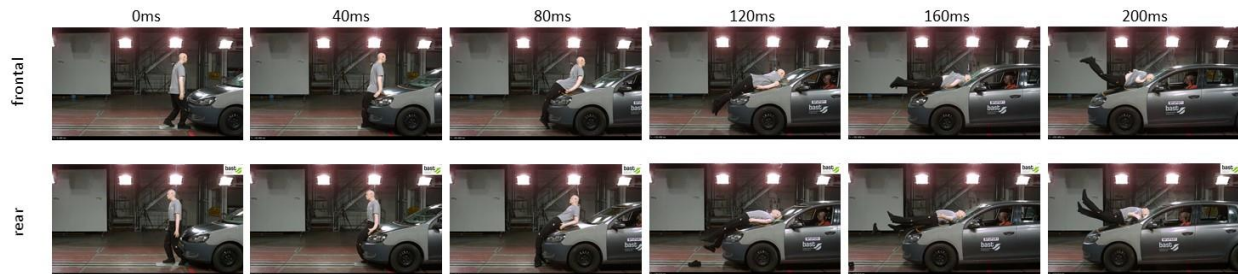
Following the initial vehicle contact of the dummy, both tests showed a scooping motion of the dummy onto the vehicle front followed by a wrap around sequence. This sequence began with the pelvis striking the BLE (SUV) or the front section of the bonnet (Sedan), followed by the left arm/elbow bracing on the bonnet and subsequent contact of the upper torso/chest with the bonnet surface. The final head impact occurred on the rear edge of the bonnet/cowl (small SUV) or against the windscreen (Sedan), respectively. Due to the small SUV's greater approach angle and increased ground clearance, the dummy's lower extremities were initially drawn underneath the vehicle (see Figure 6), resulting in a delayed wrapping around and a later vehicle rebound compared to the Sedan:



*Figure 6. Comparison of impact situation 40, 80 and 120 ms after first dummy contact: small SUV vs. Sedan.*

### Timing – frontal and rear impacts

Figure 7 depicts the kinematics during frontal (longitudinal, opposing direction) and rear (longitudinal, same direction) dummy impact:



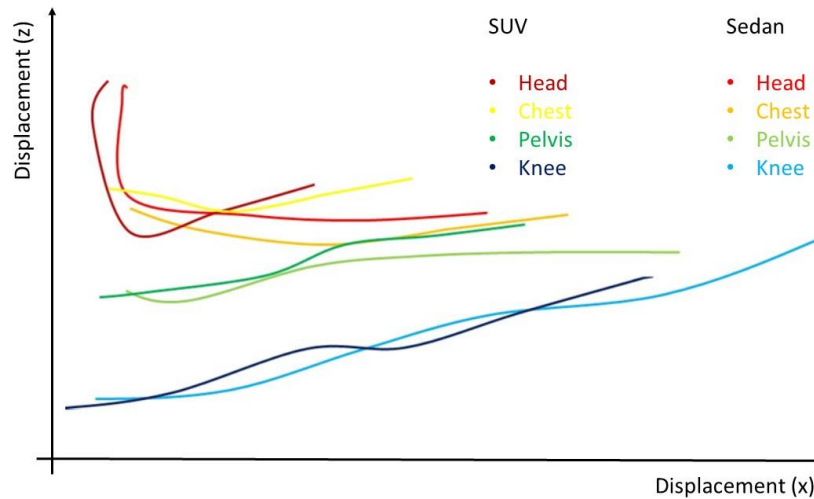
*Figure 7. Dummy kinematics during frontal and rear crash tests with opposite dummy orientation.*

In the initial phase of the impact from the rear, primarily due to early knee flexion resulting from the backward leg orientation, an accelerated wrapping around compared to the impact from the front could be observed. At approximately 40 ms, the dummy had already been scooped up to hip level, whereas the dummy that was impacted frontally remained largely in an upright position at this point. However, the subsequent motion sequence

and wrapping process in the rearward impact were delayed by the bracing of the elbows on the bonnet, altogether causing the head impact to occur almost simultaneously with the head impact in the frontal collision.

**Trajectories – lateral impacts**

A comparison of the dummy’s motion in both – Sedan and small SUV - lateral impacts is intended to verify the influence of the frontend geometries and can be approximated by tracking the markers affixed to the dummy’s head, chest, pelvis, and knees.



**Figure 8. Approximated marker-based point tracking of Primus Unbreakable during lateral impacts.**

As shown in Figure 8, the dummy’s trajectory relative to the small SUV was overall higher than relative to the Sedan. Upon impact with the rear edge of the small SUV bonnet, the head bended downward below the height level recorded for the Sedan. However, in the subsequent crash phase, the dummy was propelled upward with its torso and lower extremities in both tests and was then thrown forward (small SUV, see Figure 9) or slipped laterally (Sedan, compare Figure 10).



**Figure 9. Dummy trajectories during small SUV impact.**



Figure 10. Dummy trajectories during Sedan impact..

### Injury severities

The Primus dummy used in the vehicle tests was instrumented with accelerometers in the head, chest and pelvis. Accelerations in the chest and pelvis appear to be of limited suitability as meaningful injury criteria: however, since no alternative criteria were available, they were historically employed in the Hybrid II occupant dummy for thoracic injury. The threshold of 60 g did not represent a biomechanical limit. Nevertheless, it may generally be assumed that lower acceleration values are typically associated with reduced injury risk.

For an initial assessment of the injury risk during impact against different vehicle geometries, the recorded dummy accelerations in the collisions with the two test vehicles were compared as a reference to the observations reported by IIHS [7]. To exclude additional influencing factors such as pedestrian orientation and impact speed, the comparison was limited to the lateral impacts against the Sedan (low and sloped vehicle front) and small SUV (medium-high and blunt vehicle front) at an identical vehicle speed of 40 km/h.

Figure 11 depicts the time histories of the resultant dummy head accelerations in the aforementioned tests:

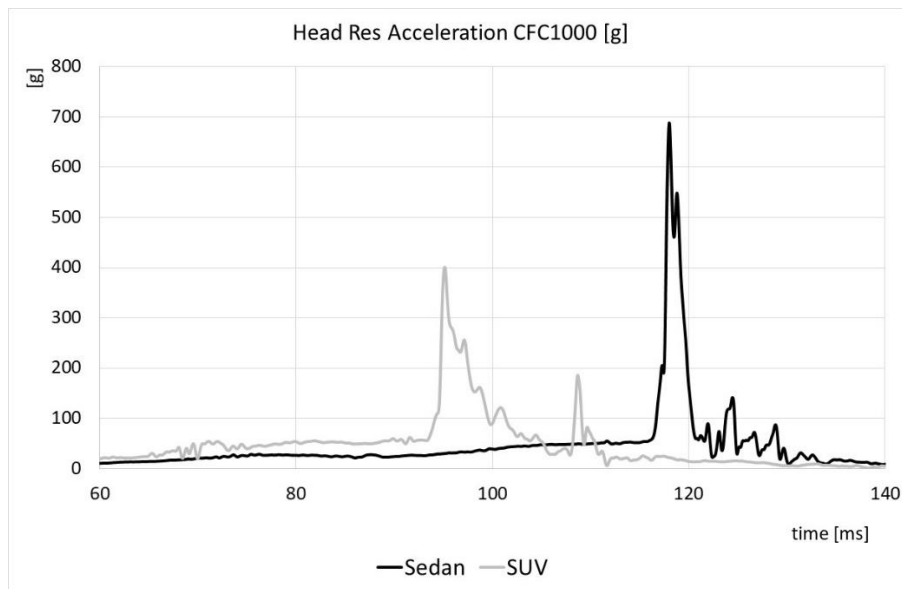


Figure 11. Resultant head accelerations during lateral impacts at 40 km/h.

While the maximum head loading in the test with small SUV occurred significantly earlier than in the Sedan test ( $\Delta t = 23$  ms), it was considerably lower (400 g vs. 686 g).

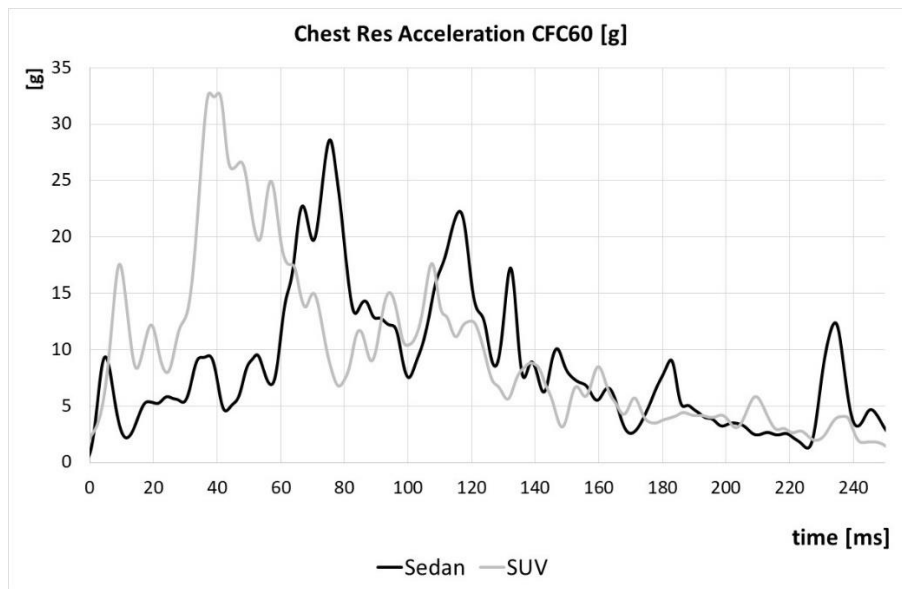
Likewise, the HIC15 ( $= \max_{t_1, t_2} \{ (t_2 - t_1) * \left[ \frac{\int_{t_1}^{t_2} A_R * dt}{t_2 - t_1} \right]^{2.5} \}$ ) was calculated to be much higher in the Sedan test (10,232) compared to the small SUV (3,797). This was unexpected, given that the head impact on the Sedan occurred almost

centrally on the supposedly compliant windscreen (Figure 12, left), whereas in the small SUV it was located on the rear edge of the bonnet (Figure 12, right) which is generally considered significantly stiffer.



**Figure 12. Head contact at 40 km/h lateral impacts.**

The exceptionally high readings in all reported tests must be interpreted with caution: the head structure of the Primus Unbreakable, characterized by an extremely thin scalp and a rigid plastic skull, is not comparable to that of crash test dummies or standardized pedestrian protection headforms. This will be further investigated in a follow-up study. The resulting chest accelerations from both tests are shown in Figure 13. The maximum loadings occurred approximately 35 ms earlier in the small SUV test and were higher than with the Sedan (32 g vs. 28 g). However, based on time histories, these differences appear moderate and remain below a hypothetical threshold of 60 g (Hybrid II) in both cases.



**Figure 13. Resultant chest accelerations during lateral impacts at 40 km/h.**



**Figure 14. Chest contact at 40 km/h lateral impacts.**

The resulting pelvis accelerations are summarized in Figure 15:

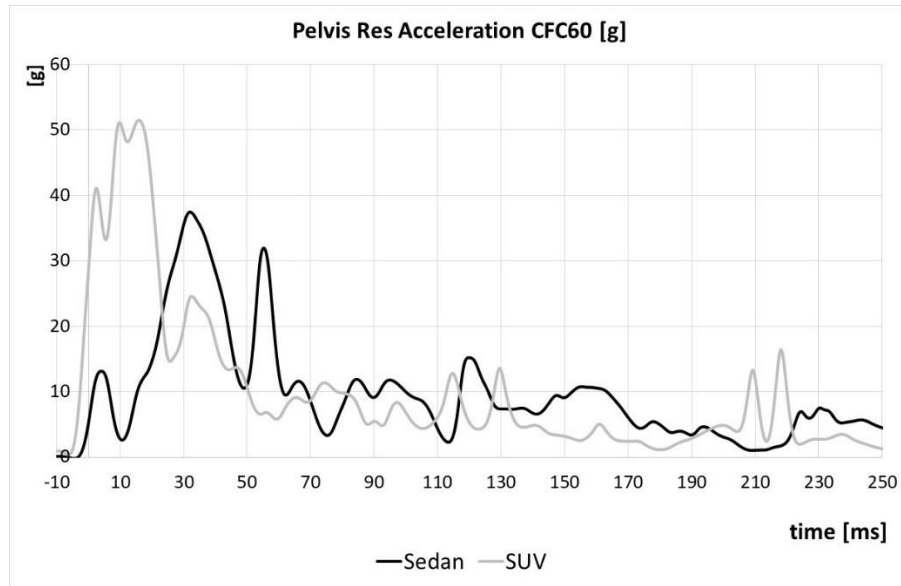


Figure 15. Resultant pelvis accelerations during lateral impacts at 40 km/h.

Due to the front-end geometry of the small SUV, the pelvis impact occurred close to the BLE and earlier than against the Sedan (maximum load at  $\Delta t = 16$  ms), see also Figure 16. The maximum pelvis acceleration during the small SUV impact was likewise significantly higher (51 g vs. 37 g).

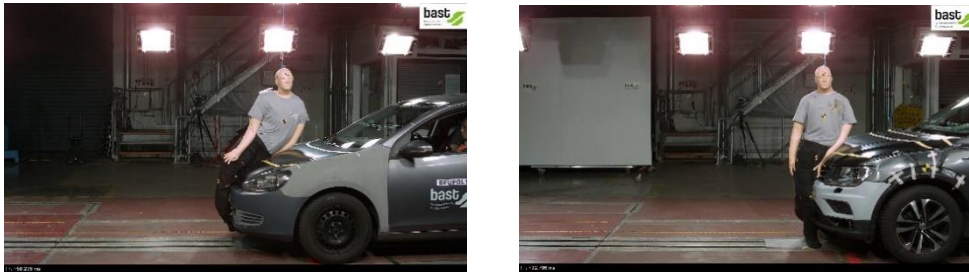


Figure 16. Pelvis contact at 40 km/h lateral impacts.

## DISCUSSION

An analysis of the performed full-scale vehicle to dummy tests shows differences in impact kinematics and dummy trajectories. For instance, the dummy's lower extremities are pulled underneath the small SUV, which delays its overall wrap around process. The pelvis impacts the presumably stiff leading edge of the small SUV, and the dummy's trajectory for this higher and blunter vehicle exceeds that for the Sedan. These aspects may provide initial indications of increased injury severity, particularly to the lower extremities, pelvis, and head; however, this assumption requires further investigation considering material properties and deformation zones.

Based on the recorded head, chest, and pelvis accelerations and their comparison in the two lateral impacts at identical vehicle speeds, the higher peak values suggest a higher injury potential for the small SUV regarding chest and pelvis; for head impact, the test results do not support this assumption. However, the resultant head accelerations measured in the Primus dummy and the derived HIC values do not withstand scrutiny regarding their biofidelity. A comparison of all Primus dummy tests with a total of five PMHS tests and ten tests using the POLAR-II pedestrian dummy against two vehicle fronts (SUV and small Sedan) from a meta-study [10] yields the results shown in Table 4:

**Table 4.**

*Comparison of impact locations and head loadings in tests with PMHS, Polar-II pedestrian dummy [10] and Primus Unbreakable against different vehicle representatives of Sedan and SUV categories*

Vehicle	Test object	Standing height	Vehicle speed	Head impact area	WAD	HIC <sub>15</sub>
Sedan	POLAR-II	173	11,1m/s	WS	1930	1437
Sedan	POLAR-II	174	11,1m/s	WS	1940	1447
Sedan	POLAR-II	174	11,1m/s	WS	1970	1321
Sedan	POLAR-II	174	11,1m/s	WS	1970	1749
Sedan	POLAR-II	179	11,1m/s	WS	2130	1091
Sedan	PMHS	187	11,1m/s	WS	2410	824
Sedan	PMHS	179	11,1m/s	WS	2200	3647
Sedan	PMHS	186	11,1m/s	WS	2320	511
<b>Sedan</b>	<b>Primus</b>	<b>172</b>	<b>11,1m/s</b>	<b>WS</b>	<b>2010</b>	<b>10232</b>
Sedan	Primus	172	11,1m/s	WS	2098	7776
Sedan	Primus	172	11,1m/s	WS	1970	7784
Sedan	Primus	173	11,1m/s	WS	2010	4763
SUV	POLAR-II	173	11,1m/s	Bonnet	1685	577
SUV	POLAR-II	172	11,1m/s	Bonnet	1660	826
SUV	POLAR-II	171	11,1m/s	Bonnet	1665	752
SUV	POLAR-II	174	11,1m/s	Bonnet	1700	1704
SUV	POLAR-II	179	11,1m/s	Bonnet	1850	1642
SUV	PMHS	177	11,1m/s	Bonnet	1860	3694
SUV	PMHS	176	11,1m/s	Bonnet	1845	745
<b>SUV</b>	<b>Primus</b>	<b>172,5</b>	<b>11,1m/s</b>	<b>Bonnet</b>	<b>1760-1810</b>	<b>3797</b>
SUV	Primus	172	13,9m/s	Bonnet/WS	1780-2000	17131

The lateral impact tests with the Primus dummy at 40 km/h vehicle speed (bold frames in Table 4) correspond to those with the POLAR-II dummy and PMHS in terms of head impact areas (bonnet, windscreen) and contact regions (WAD); moreover, the tendency of the head impact point being further rearward on the Sedan compared to the SUV is similarly reproduced with the Sedan and small SUV from the present study (WAD 2010 vs. WAD 1760–1810). However, the HIC values in all tests with the Primus dummy significantly exceed those reported in the meta-study, with two exceptions (second PMHS test against the Sedan and first PMHS test against the SUV). Nevertheless, the resulting accelerations in these two tests remained well below 350 g and thus below the readings from the lateral impact tests as observed in this study.

The measurements for chest and pelvis support the findings of IIHS, which indicate that higher injury severities of the upper body and pelvis, based on accident data, are more frequently associated with high and blunt vehicles than with low and sloped ones [7].

The greatest possible influence of an alternative dummy orientation was examined using frontal and rearward impacts on the Sedan. An initially faster wrap-around in the rearward impact, caused by early knee flexion, was compensated

by the dummy's subsequent support with the elbows, resulting in the head impact on the windshield occurring at similar times in both tests.

## **CONCLUSIONS**

Vehicle safety assessments for passive protection of VRU currently rely exclusively on pedestrian impactor tests in both, consumer information programmes as well as legislation. These impactors represent individual body regions (head, pelvis, lower extremities) and offer advantages in repeatability, reproducibility, costs and efforts compared to full-scale vehicle tests with whole body dummies. However, their limited biofidelity regarding kinematics, load distribution and injury prediction is a drawback. In particular, the influence of vehicle geometry on pedestrian safety appears underrepresented due to the absence of full-body kinematics in component tests. The consideration of full-body kinematics is expected to influence both: impact areas on the vehicle as well as impact parameters of the body parts, e.g. impact angle and impact speed.

The vehicle tests conducted with the "Primus Unbreakable" aimed to investigate the influence of frontend geometry on pedestrian impact kinematics and injury severity. A total of four tests was performed with two vehicles of different categories, varying pedestrian orientation and trajectory.

The tests conclude the frontend geometry being a potential factor with considerable significance for affecting pedestrian impact kinematics and injury severity in a crash. Vehicles with greater ground clearance and a corresponding BLE relative to the pedestrian's center of gravity tend to draw the lower extremities underneath the vehicle, thereby influencing the wrap around process and contact locations between dummy and vehicle. Higher and blunter vehicles also have the potential to increase the pedestrian's flight trajectory, which may result in a greater drop height onto the vehicle or throw height onto the road surface. Based on the measured higher chest and pelvis accelerations, these vehicles may present an overall higher injury risk.

Further research is needed in this area. As initial recommendation, simulation-based parameter studies using human body models may be conducted on generic vehicle frontends to determine the influence of key frontend parameters (BLE height, bumper lead, bumper height, bonnet and windscreen angle) on impact angle, velocity and location. Adjusted test parameters could be derived or a "geometry factor" implemented within vehicle safety assessments (e.g., high leading edges and steep front profiles → increased injury risk for pelvis and thorax).

## **LIMITATIONS**

The reported study is based on a limited number of full-scale vehicle to dummy tests against two European average vehicles from different categories, only. Extremes in terms of BLE heights or bumper leads are not yet included. So far, the influence of other vehicle parameters, e.g. bonnet and windscreen angles have not been investigated. Vehicles from other categories and different pedestrian statures may enlarge the database and support the initial findings. The biofidelity of the head of the Primus Unbreakable needs to be further evaluated. A study of comparative drop tests with different headforms is in preparation.

## **ACKNOWLEDGEMENTS**

The authors would like to thank Michael Weyde from Priester & Weyde for the provision of a test vehicle and his expertise in conducting full-scale tests with the Primus dummy and Peter Schimmelpennig and Mirko Dobberstein from CTS crashtest-service.com for their efforts and support with the Primus dummy.

## REFERENCES

- [1] Federal Statistical Office of Germany DESTATIS. 2025.: Database, <https://www-genesis.destatis.de/datenbank/online/>
- [2] Global Technical Regulation No. 9. 2008. Pedestrian Safety. United Nations, <https://Unece.org>
- [3] Regulation (EU) 2019/2144 of the European Parliament and of the Council. 2019. <https://eur-lex.europa.eu>
- [4] UN Regulation No. 127. 2013-2025. Uniform provisions concerning the approval of motor vehicles with regard to their pedestrian safety performance. United Nations, <https://unece.org>
- [5] European New Car Assessment Programme: [www.euroncap.com](http://www.euroncap.com)
- [6] PRIMUS Unbreakable Biofidelic Crashtest Dummy. <https://www.crashtest-service.com/en/biofidelic-dummy/model-overview/>
- [7] Monfort S. 2024. „Vehicle front-end geometry and in-depth pedestrian crash outcomes.“ IIHS presentation during final workshop „Thorax Impactor for VRU Safety“. Munich, 24 April 2024.
- [8] Zander O., Fattorini N., Wisch M. 2026. „Windscreen fracture behaviour during impactor and full-scale vehicle to dummy tests and its significance for the safety of pedestrians and bicyclists in real-world crashes.“ Paper no. 26-112 of 28th ESV conference proceedings. Toronto, 2026.
- [9] German Insurers Accident Research (UDV) of the German Insurance Association (GDV). 1998. „Unfalltypen-Katalog. Leitfaden zur Bestimmung des Unfalltyps.“ New edition, 2016.
- [10] Kerrigan J., Arrequi-Dalmases C., Crandall J. 2012: “Assessment of pedestrian head impact dynamics in small Sedan and large SUV collisions.” International Journal of Crashworthiness Volume 17, 2012 - Issue 3.