SHORT COMMUNICATION: STAPP CAR CRASH CONFERENCE

Role of pedestrian waist and hip height relative to the vehicle front end in kinematics and torso injuries

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ABSTRACT – This study examined 127 U.S. pedestrian crashes involving model year 2009–2022 cars, SUVs, and pickups to explore how the height of the vehicle front end relative to the pedestrian's hip and waist height affected pedestrian kinematics and torso injuries. Vehicle hood leading edge (HLE) height was compared with estimates of pedestrian hip and waist heights. Vehicles with HLEs higher than the pedestrian's waist were associated with the largest proportion of AIS 2+ thorax, abdomen, and spine injuries produced by torso impacts with the front headlights, grille, and HLE. Vehicles with HLEs higher than the pedestrian's hip but lower than the waist had the next highest proportion of AIS 2+ torso injuries from impacts with the hood and cowl. Future torso impactor testing of vehicle front ends must take kinematics and injury source differences for the tallest vehicles into consideration to ensure evaluations are assessing countermeasures relevant to real-world torso injuries.

INTRODUCTION

In 2022, 7,522 pedestrians were killed in motor vehicle crashes on roadways in the United States, an 83% increase since 2009 (IIHS, 2024). U.S. consumers are increasingly choosing larger vehicles, with 73% of 2024 registrations being SUVs and pickups (HLDI, 2024). These vehicle types are associated with a greater risk of pedestrian injury compared with passenger cars (Hu and Cicchino, 2018; Monfort and Mueller, 2020). Previous examinations of U.S. pedestrian crashes using detailed measurements of striking-vehicle front-end geometry identified that vehicles with the highest hood leading edges (HLEs) and blunt shaped vehicles were more injurious, specifically for the head and torso (Hu et al, 2024; Monfort et al, 2024; Yin et al, 2017).

Historically, a pedestrian's hip height relative to the striking vehicle's front end has been a key predictor of crash kinematics and injury outcomes (Ballesteros et al, 2004; Longhitano et al, 2005; Roudsari et al, 2005). Vehicles with front ends that are taller than the pedestrian's hip height (approximately at a person's center of gravity) are more likely to throw a pedestrian to the ground, rather than slide them up the vehicle's front (Roudsari et al, 2005; Subit et al, 2008). A comparison of top selling cars, SUVs, and pickups over the last 30 years indicate that vehicle HLEs have increased on average by 10 cm, further exacerbating the problem of tall vehicles for pedestrians (IIHS, 2024).

The current study examines U.S. pedestrian crashes involving model year 2009–2022 vehicles to identify the role that HLE height relative to the hip and waist heights of the struck pedestrian plays in crash kinematics and torso injury outcomes.

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METHODS

In-depth pedestrian crash reconstructions from two U.S.-based crash datasets were used for this analysis. The Vulnerable Road User Injury Prevention Alliance (VIPA) dataset is an ongoing in-depth collection of pedestrian crashes since 2015 from Michigan involving vehicles newer than 15 years old and all pedestrian injury levels. As of July 2024, 185 pedestrian crash reconstructions have been collected. In 2022, the National Highway Traffic Safety Administration collected 92 in-depth pedestrian crashes in California, Texas, and New Jersey under the project Vulnerable Road User In-Depth Crash Investigation Study (VICIS) (Lockerby, 2023). Cases included any pedestrians struck by the front of a motor vehicle. Both datasets (VIPA and VICIS) collected police reports, scene information, and medical records as input for reconstructing the crash scenario. Experts used evidence from these data along with simulation tools to determine impact speed and pedestrian kinematics and to attribute injuries.

Cases were included if the crash configuration involved the vehicle front striking an adult-sized pedestrian who was standing, walking, or running. All pedestrians sustained at least one AIS 2+ injury. A total of 81 VIPA and 46 VICIS cases met all study criteria. These cases involved 67 cars/minivans, 40 SUVs, and 20 pickups from model years 2009 to 2022.

Measurements of the vehicle front ends were compared with the pedestrians' waist and hip heights. Vehicle HLE heights were obtained using a method outlined in Hu et al (2024) and compared with the pedestrian height. If pedestrian height was unknown (n = 34), it was assumed to be 162 cm for adult females and 175 cm for adult males (Alvin and Henry Dreyfuss Associates, 2002). Pedestrian hip height was estimated at 52% of total height (Alvin and Henry Dreyfuss Associates,

2002) and waist height was estimated at 60% of total height (Gordon et al, 1989).

Vehicles were assigned to three categories relative to the pedestrian (percent of pedestrians in category with forward projection kinematics shown in parentheses): *HLE < Ped* — both pedestrian hip and waist above the HLE (12%); *HLE = Ped* — pedestrian hip below and waist above the HLE (24%); and *HLE > Ped* — pedestrian hip and waist below the HLE (33%).Vehicle kinematics, MAIS by AIS-coded body region, and injury source by body region were analyzed. A combined MAIS torso category was created from the combination of thorax, abdomen, and spine. Statistical comparisons were made using a logistical regression predicting the presence of AIS 2+ injury. A chi-squared test was used to assess the differences in injury sources by relative height categories.

RESULTS

Figure 1 compares the probability of MAIS 2+ thorax, abdomen, spine, and combined torso injuries by relative vehicle height. Average ISS is shown.

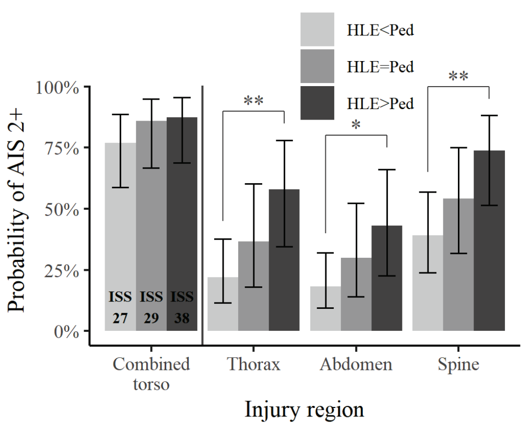

Figure 1. Probability of MAIS 2+ injured pedestrians with MAIS 2+ torso injuries by vehicle height category

*** p<0.05; ** p<0.01**

Table 1 provides counts of the maximum AIS torso injury by vehicle component. Figure 2 depicts the typical pedestrian kinematics associated with each vehicle height.

As vehicle front-end height relative to the struck pedestrian increased, the risk of AIS 2+ thorax ($p < 0.01$) abdomen ($p < 0.05$), and spine ($p < 0.01$) injuries also increased. Fewer hood/cowl but more HLE torso injury sources were observed, as vehicle height relative to the pedestrian was greater ($p < 0.001$). Only pedestrians with waist heights below the HLE had torso injuries from the headlights and grille.

Table 1. Source of MAIS 2+ torso injury by vehicle height category

	Headlight/ grille	HLE	Hood/ cowl	Greenhouse	Ground	None
HLE < Ped	0	4	31	8	3	20
HLE = Ped	0	8	15	1	1	7
HLE > Ped	9	7	7	0	1	3

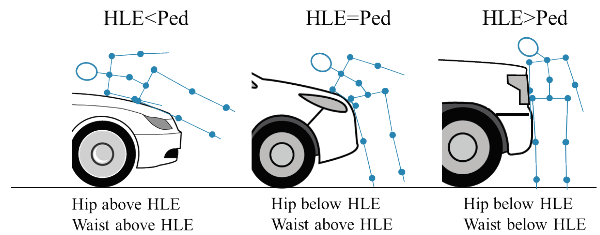

Figure 2. Typical pedestrian kinematics for each vehicle height category

DISCUSSION

This study investigated the effect of vehicle front-end height relative to the hip and waist heights of the pedestrians they struck on kinematic differences and torso injury risk. We found that when the vehicle HLE was below the waist, the upper body was more likely to wrap around the top of the front end. In contrast, when vehicle front ends were tall enough to concurrently impact the hip and rib cage, the upper body tended to be constrained from wrapping around the vehicle. Instead, these cases produced torso injuries from primary impacts with components on the vehicle front (primarily the headlights and grille).

Overall injury and kinematics trends were consistent with previous studies showing that taller vehicles are associated with increased torso injuries and more forward projection kinematics (e.g., Monfort et al, 2024). The current study is the first to specifically examine late model SUVs and pickups in the context of impactor testing scenarios to identify that within this group of vehicles, the tallest vehicles (large SUVs and pickups) are associated with different vehicle torso injury sources. Older datasets of U.S. pedestrian data, such as PCDS, contain limited SUV and pickup cases because those vehicle types were not as popular in the 1990s. Recent pedestrian datasets from Europe and Japan contain some SUVs but lack pickups, often citing pickups as a uniquely "American trend" though these markets have commercial trucks.

Future research should focus on identifying the unique impact conditions associated with the tallest vehicles so that test and evaluation protocols can be modified to represent relevant real-world conditions. Effective vehicle-based countermeasures to reduce torso injuries for the tallest U.S. vehicles would likely require different strategies compared with medium or short vehicles. Applying a thorax impactor test and evaluation protocol, for example, is a not a one-size-fits-all solution for the range of U.S. vehicles. For the greatest real-world relevance, tall vehicles should have their pedestrian crashworthiness determined primarily by their front-end components (e.g., headlights, grille, and HLE). In contrast, medium and short vehicles should be evaluated according to the crashworthiness of their components on the top of the front end, hood, and cowl, and with an angled impactor to represent the kinematics of a glancing torso impact. Test protocols that exempt tall vehicles or assess vehicles on irrelevant test conditions are missed opportunities to address a significant portion of pedestrian fatalities, especially as consumers continue to choose larger and taller vehicles.

The current research describes observations of real-world torso injury sources for the range of vehicle heights relative to pedestrians, which can guide vehicle designers to focus countermeasure efforts on relevant real-world vehicle components by vehicle size. Additional research is needed to understand the potential of vehicle countermeasures to mitigate torso injuries, particularly from the tallest vehicles.

The real-world crashes evaluated in this analysis are from two non-representative samples of U.S. pedestrian data; therefore, observations cannot be directly scaled to any larger population of pedestrian crashes. Although this dataset contains a variety of SUV and pickups less than 15 years old, designs may not reflect the most recent geometries of newer SUV and pickups.

CONCLUSION

This study examined U.S. pedestrians struck by cars, SUVs, and pickups for torso injury patterns. Vehicles with HLEs taller than the struck pedestrian waist are associated with the largest proportion of AIS 2+ thorax, abdomen, and spine injuries resulting from pedestrian torso impacts with the front headlights, grille, and HLE, compared with vehicles with HLEs below the waist with injuries from the hood and cowl.

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