Tab 17

From: stanton.glantz@sonic.net <stanton.glantz@sonic.net>
Sent: Tuesday, May 5, 2026 9:29 AM
To: Driller, Brigitte@CATC <Brigitte.Driller@catc.ca.gov>
Cc: Behrens, Justin@CATC <Justin.Behrens@catc.ca.gov>
Subject: RE: Vehicle Weight Safety Study

Thanks for sending this. I did a quick read of the report and Appendix B and was surprised that the authors did not present any formal statistical analysis of the association between vehicle weight and injury risk.

On PDF page 55 of Appendix B they state: "**Due to the scope and timeline, only descriptive analysis was conducted, meaning that no causal relationships were identified,** and other factors may have a played a role in explaining some of the trends highlighted. Additional challenges occurred in relation to the crash data used. These included inconsistent vehicle type coding in SWITRS over time. This resulted in the exclusion of certain vehicles and our analysis period starting in 2010 for breakdowns by vehicle type. Additional challenges include the granularity of SWITRS reporting, specifically: the lack of victim race and ethnicity data and no estimated speed for cars at the time of impact."
As a result, the primary conclusion in the main report that causality cannot be asserted is very misleading. The fact is that they didn't look.

I spent 34 years on the CalEPA Scientific Review Panel on Toxic Air Contaminants which is legally charged with providing independent peer review of risk estimates for proposed toxic air contaminants in California. (I also wrote two statistics textbooks.) If this report had been sent to me for peer review, I would have sent it back to the authors to do a proper analysis.
While the SWITRS dataset does not have speed, it does have whether there was a speeding violation, which could have been used as a proxy to get a reasonable estimate of the effects of weight, the primary goal of the analysis.

The attached paper from the Insurance Institute for Highway Safety, which is not cited, provides an excellent model.

I hope this is helpful.

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A modern injury risk curve for pedestrian injury in the United States: The combined effects of impact speed and vehicle front-end height

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ABSTRACT

Objective: Estimating the probability of pedestrian injuries at different impact speeds is important for research and regulatory efforts related to infrastructure and vehicle design. However, a risk curve is only valuable if it is based on crash data that accurately represent the current vehicle fleet. This study, therefore, aimed to provide an updated estimate of pedestrian injury risk at different severity levels using recent crash data from U.S. roads. *Method:* We analyzed 202 pedestrian crashes to generate an estimate for the link between injury outcomes and impact speed. Measurements of the vehicles involved were used to examine the moderating effect of hood leading edge height. *Results:* We generated injury risk curves by impact speed at three different severity thresholds (MAIS 2+F, MAIS 3+F, and fatal). As expected, impact speed strongly predicted injury risk, and hood leading edge height significantly increased the risk of pedestrian injury overall as well as the potency of impact speed for serious injuries. Formulas are included to generate injury risk curves for pedestrians of different ages and sexes, and for vehicles of different hood leading edge heights. *Conclusions:* Our risk curves for pedestrian injury risk are shifted leftward (i.e., with injury inflicted at lower impact speeds) compared with contemporary estimates of pedestrian injury risk in Europe. This difference is likely due to the prevalence of larger, taller vehicles in the United States.

1. Introduction

When a pedestrian is struck by a motor vehicle, their risk of injury is strongly related to the speed at which they were struck. The relationship between impact speed and injury risk has been the subject of research for many decades, with risk curves being recalculated as vehicle design and fleet composition continue to change over time (Lubbe et al., 2022; Rosén & Sander, 2009; Yaksich, 1964). The most recent analysis to date (Lubbe et al., 2022) involved crash data from 1999–2020 extracted from the German In-Depth Accident Study (GIDAS). These results were broadly consistent with earlier work using German crash data, with a 10% pedestrian fatality risk at a 56-km/h impact speed (e.g., Hannawald & Kauer 2004; Rosén & Sander, 2009). However, the most recent injury risk curve for pedestrians in the United States was calculated using crashes from 1994–1998 from the Pedestrian Crash Data Study (PCDS) (Tefft, 2013). For an injury risk curve to apply to a population, it must be created using data with a representative sample of vehicles, and so the current study was conducted to provide an up-to-date injury risk curve for pedestrians in the United States.

The vehicle fleet in the United States is singular in its prominence of large passenger vehicles, of SUVs in particular (Li et al., 2016). Indeed, the prevalence of SUVs in the United States has been steadily rising, increasing from 19–35% of the registered passenger-vehicle fleet between 2010 and 2023 (Insurance Institute for Highway Safety, 2024a). Even non-SUVs in the United States have been getting larger and heavier over this interval, with the average registered car 4% heavier and the average registered pickup truck 13% heavier and 7% larger (width × length; IIHS, 2023). Large pickup trucks have also been getting attention from researchers and the media for their large, flat front ends that increase pedestrian injury risk (e.g., Hu et al., 2024; Monfort et al., 2024; Tyndall, 2024).

Consumers in the United States are increasingly choosing vehicles with characteristics associated with more severe pedestrian injuries (IIHS, 2024a). SUVs and pickup trucks are responsible for a disproportionate number of pedestrian injuries and fatalities. By some estimates, these vehicles are 2–3 times more likely to kill a pedestrian in a crash compared with smaller cars (Lefler & Gabler, 2004; Roudsari et al., 2004). The risk from these vehicles largely stems from their hood

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leading edges being above the centre of gravity of the pedestrians they strike, producing direct frontal impacts with the pedestrians' torsos and being more likely to throw them forward in front of the decelerating vehicle (Hu et al., 2024; Monfort et al., 2024; Roudsari et al., 2005), putting them at greater risk of being subsequently run over. Larger and taller vehicles are also more likely to hit pedestrians while turning at intersections and when pedestrians are along the edges of travel lanes, suggesting that these vehicles might contribute to reduced driver visibility in some situations (Hu & Cicchino, 2022). The prevalence of taller vehicles in the United States is likely to shift the associated injury risk curves, with more severe injuries being produced by lower impact speeds compared with curves generated from data in Europe and elsewhere.

Having an accurate estimate for the relationship between impact speed and injury risk for pedestrians is important for numerous reasons. Under the Safe System approach, selecting a speed limit for roads in urban centres that aligns with injury risk tolerances will further the goal of reducing harm on the roadways. Similarly, accurate injury risk curves allow researchers and regulators to refine test protocols for vehicle evaluations, such as component impactor tests, and to develop vehicle countermeasures at crash speeds associated with injury. The efficacy of certain crash avoidance systems, like automatic emergency braking (AEB), is also dependent on understanding how much a reduction in speed maps onto the reduction in injury probability. In sum, the goal of the current study was to calculate updated U.S. pedestrian injury risk curves that can be used to inform research and legislation on infrastructure improvements, crash avoidance technologies, and vehicle design countermeasures.

2. Method

2.1. Data

Data were aggregated from two vulnerable road user crash databases, which each recorded impact speed, detailed injury data, demographic information, as well as make and model information for the striking vehicle. We used the combined dataset to produce injury risk curves.

2.2. Vulnerable road user injury prevention alliance

The Vulnerable Road User Injury Prevention Alliance (VIPA) provided pedestrian crash data as a part of the International Centre for Automotive Medicine (ICAM) Pedestrian Consortium. These data contained detailed records of Michigan crashes between 2015 and 2022 where police were called to the scene, including police reports, photographs, scene information, medical records, and injury attribution. Vehicle striking speed was estimated by a panel of experts using evidence from the scene and crash reconstruction software that iteratively simulated the crash at different speeds until the simulated pedestrian impact points and kinematics matched the physical evidence collected from the case. Of the 149 crashes included from the VIPA database, 89 involved passenger cars, 14 involved pickup trucks, and 46 involved SUVs. The majority (92%) of pedestrians in this sample suffered some level of injury; the average Maximum Abbreviated Injury Scale (MAIS) score was 2.9 (interquartile range [IQR] = 1–4).

2.3. Vulnerable road user in-depth crash investigation study

The Vulnerable Road User In-Depth Crash Investigation Study (VICIS) dataset is a project funded by the National Highway Traffic Safety Administration (NHTSA) operating under the Crash Investigation Sampling System (CISS). VICIS collected data on crashes that occurred in 2022 from four sampling sites; the data collected included medical records, police reports, scene diagrams, photos, and measurements from investigators. Sampling sites were situated in California (1), New Jersey (1), and Texas (2). Vehicle impact speeds were estimated from event data recorders, formulas for pedestrian throw distance, and other evidence. Crashes were limited to cases where the striking vehicle was of model year 2004 or newer. Of the 53 crashes included from the VICIS database, 28 involved passenger cars, 4 involved pickup trucks, and 21 involved SUVs. Consistent with the patterns observed in the VIPA dataset, the majority (96%) of pedestrians in the VICIS dataset suffered some level of injury; the average Maximum Abbreviated Injury Scale (MAIS) score was 3.0 (IQR = 1–4).

2.3.1. Combined dataset

The combined sample contained 202 crashes (119 male, 83 female) with pedestrians aged between 16 and 92 (IQR = 26–57 years) and vehicles of model year between 2004 and 2022 (IQR 2008–2015). The average impact speed of these crashes was 43 km/h (IQR = 19–61 km/h). Only crashes where the pedestrian was struck by the front of a vehicle moving 5 km/h or faster were included in the final analysis. Cases were also filtered to exclude crashes involving a pedestrian aged 15 years or younger. This exclusion was applied because the shorter stature of children would affect the nature of the threat posed by vehicle height (i.e., relative height matters; Monfort et al., 2024).

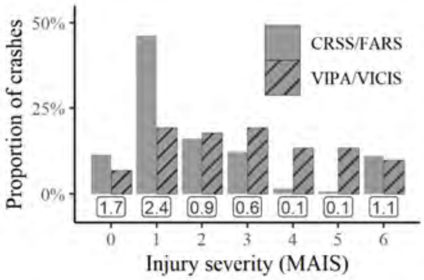
2.4. Vehicle measurement

Exemplar photographs of the vehicle models involved in the VIPA and VICIS crashes were used to assess the height of their hood leading edges. The hood leading edge was defined as the distance between the ground and the inflection point where the front end transitioned to the hood, representing the point around which a pedestrian might pivot in a crash. More details about the development and validation of the measurement procedure can be found in Hu et al. (2024).

2.5. Case weighting

A common shortcoming of injury risk assessments is that injury databases tend to oversample injury crashes (Rosén et al., 2011). This is the case for the datasets employed by the current study (both VIPA and VICIS): crashes that produce a police report are more likely to involve a severe injury than crashes that resolve without one. In fact, the VIPA database deliberately oversamples severe crashes to obtain a larger sample of fatalities than would result from a simple random sample, further skewing the sample. Were these data used without adjustment, the resulting crash injury risk curves would overestimate the chance of injury.

To compensate for the oversampling of severe and fatal crashes, we estimated the population risk of nonfatal and fatal injuries for 2015–2022 using the Crash Reporting Sampling System (CRSS) and the Fatality Analysis Reporting System (FARS), respectively. These population estimates were used to generate weights for our regression models. CRSS is a nationally representative weighted probability sample of police-reported crashes that occur in the United States, while FARS is an annual census of roadway fatalities; both are overseen by NHTSA. These data were filtered to include only frontal crashes of a passenger vehicle into a pedestrian and weighted according to CRSS guidelines to produce a representative distribution of crash injury severity at the population level. Population injury severity data were converted from the KABCO scale to the MAIS using a procedure developed by NHTSA (for details, see Wang, 2023). Together, these datasets provided us with a population distribution of pedestrian crash injury severity. Comparing this population distribution against that of our sample showed that, as expected, crashes in the VIPA and VICIS databases were disproportionately likely to produce a severe injury (Fig. 1). VIPA and VICIS crashes were likewise less likely than expected to produce mild injuries (i.e., MAIS 1) compared with what would have been expected in the general population. To address this inequity, we used the ratio between population and sample crash severity prevalence as weights in our



Note. Numeric annotations refer to the ratio between the two proportions.

Fig. 1. Comparison of MAIS scores between population and sample estimates.

regression models. Crash counts by injury severity and dataset, weighted and unweighted, can be seen in Table 1.

2.6. Injury risk prediction

Logistic regression models were used to estimate injury risk for three levels of severity: moderate-to-fatal injury (MAIS 2+F), serious-to-fatal injury (MAIS 3+F), and fatal injury (Lubbe et al., 2022). Impact speed, hood leading edge height, and the interaction between the two were the primary predictors of interest—a significant interaction between these variables could suggest that vehicle height amplifies the risk associated with impact speed. Additional covariates were included to improve the validity of the models: pedestrian sex (male vs. female) and age.

3. Results

A higher impact speed was associated with increased risk of injury at all three severity thresholds. A 50% risk of MAIS 2+F, MAIS 3+F, and fatal injuries was reached at 35 km/h (22 mph), 49 km/h (30 mph), and 68 km/h (42 mph), respectively (Fig. 2). A threshold that is commonly used to characterize a safe impact speed is the speed at which a pedestrian reaches a 10% risk of MAIS 3+ injury (Academic Expert Group, 2019; Lubbe et al., 2022): in our sample, this threshold was reached at 24 km/h (15 mph). Consistent with past research, older pedestrians were at significantly greater risk for injury at all thresholds (Niebuhr et al., 2016; Sklar et al., 1989); there were no meaningful injury risk differences between males and females.

3.1. Hood leading edge height

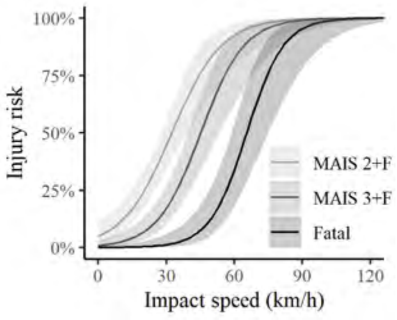
For pedestrians, taller vehicles were associated with a significantly greater probability of both MAIS 2+F ($p = 0.083$) and MAIS 3+F ($p = 0.033$) injuries (Table 2). These effects represent an increase in overall crash injury risk when vehicles with higher hood leading edges are involved. For reference, the difference between the median passenger-car height in our sample and the median pickup truck height in our sample, 33 cm (13 in.), was an increase in MAIS 2+F injury probability from 59% to 82% and an increase in MAIS 3+F injury probability from 29% to 60%. Although the main effect of hood leading edge height fell in the same direction for fatal injury risk (increasing quite substantially from 2.7% to 12%), there was sufficient variation in this effect that it was not statistically significant ($p = 0.153$).

Table 1
Crash counts by MAIS score for each database and their combination.

MAIS	VIPA	VICIS	Combined
0	12	2	14 (23.8)
1	26	13	39 (93.6)
2	29	7	36 (32.4)
3	27	12	39 (23.4)
4	21	6	27 (2.7)
5	21	6	27 (2.7)
6	13	7	20 (22.0)

Note. The weighted counts from the combined dataset are depicted in parentheses alongside the unweighted counts.

Pedestrian injury risk curves for MAIS 2+F, MAIS 3+F, and fatal crashes



Note. Shaded regions represent 95% confidence intervals.

Fig. 2. Pedestrian injury risk curves for MAIS 2+F, MAIS 3+F, and fatal crashes.

Table 2
Logistic regression results for pedestrian crash risk for MAIS 2+F, MAIS 3+F, and fatal injuries.

	OR	95% CI	p	
Impact speed (km/h)				
MAIS 2 + F	1.09	[1.06, 1.12]	0<.001	***
MAIS 3 + F	1.10	[1.07, 1.13]	0<.001	***
Fatal	1.13	[1.09, 1.20]	0<.001	***
HLE height (cm)				
MAIS 2 + F	1.04	[1.00, 1.08]	0.083	†
MAIS 3 + F	1.04	[1.01, 1.08]	0.033	*
Fatal	1.05	[0.98, 1.12]	0.153	
Sex (male vs. female)				
MAIS 2 + F	1.05	[0.50, 2.19]	0.902	
MAIS 3 + F	0.89	[0.34, 2.28]	0.805	
Fatal	1.38	[0.30, 6.42]	0.676	
Age (years)				
MAIS 2 + F	1.02	[1.00, 1.05]	0.034	*
MAIS 3 + F	1.03	[1.01, 1.06]	0.018	*
Fatal	1.03	[1.00, 1.07]	0.087	†
Impact speed × HLE height				
MAIS 2 + F	1.00	[1.00, 1.00]	0.163	
MAIS 3 + F	1.00	[1.00, 1.01]	0.047	*
Fatal	1.00	[1.00, 1.00]	0.988	

Note. OR = odds ratio; CI = confidence interval; HLE = hood leading edge.
*** $p < 0.001$; * $p < 0.05$; † $p < 0.10$.

Hood leading edge height also produced a steeper injury risk curve at the MAIS 3+F injury risk threshold (i.e., an interaction; $p = 0.047$). Going from a 24 km/h (15 mph) crash to a 56 km/h (35 mph) crash increased MAIS 3+F injury risk from 9.4% to 52% (5.5 times) for a vehicle with the height of the median passenger car but from 11% to 91% (8.3 times) for a vehicle with the height of the median pickup truck. The effect for MAIS 2+F was similar, albeit smaller and not statistically significant.

The interaction between hood leading edge height and impact speed means that vehicle size was less relevant for relatively slow impact speeds. That is, although the impact speed at which a pedestrian could expect a 10% chance of serious injury (i.e., the "safe impact speed") was 24 km/h (15 mph) in the overall sample, this threshold differed only by a small amount between the median passenger car and median pickup truck: 25 km/h (16 mph) and 23 km/h (14 mph), respectively. In sum, vehicle height significantly increased the risk of pedestrian injury overall as well as the potency of impact speed for taller vehicles, particularly with respect to MAIS 3+F injury risk at impact speeds higher than about 30 km/h (19 mph).

3.2. Comparison with past findings

The injury risk curves calculated from our data were shifted 20–40% leftward (i.e., with U.S. pedestrians more prone to injury overall) compared with those calculated by Lubbe et al. (2022) using GIDAS data. This difference was expected, given the differences in both vehicle size and fleet composition between the United States and Germany (e.g., Li et al., 2016). Interestingly, splitting our overall injury risk curve into two—one for our sample's median-height pickup (109 cm) and one for our sample's median-height passenger car (75 cm)—produced a U.S. passenger-car risk curve that approximates the curve produced by the German sample, which itself was mostly (87%) passenger cars (Fig. 3). This parity suggests that the difference between injury risk curves for the United States and Germany (and potentially other European countries) is largely related to the size of the vehicles in each fleet.

Compared with a previous estimate of fatal crash injury from U.S. crash data (Tefft, 2013), we found that pedestrians were slightly less likely to be fatally injured at lower speeds, but that the risk estimates converged at higher speeds (Table 3).

$$1+e^{(-3.28+.123*(50\ \ 42.79)+.047*(90\ \ 85.25)+0.319*(0\ \ .59)+0.030*(30\ \ 42.42)+0.000((50\ \ 42.79)*(90\ \ 85.25)))}\Big)^{1}$$

3.3. Formulas for risk curve calculation

The following formulas can be used to calculate injury risk at different severity thresholds for a given impact speed (km/h), hood leading edge height (cm), pedestrian sex (male = 1, female = 0), and pedestrian age (years). Note that our predictors were mean centered, and anyone using these formulas should subtract our sample mean values included in Table 4 from the values they input.

$$p(MAIS2+F) = \ 1+e^{(0.686+0.083*X_1+0.034*X_2+0.047*X_3+0.023*X_4+0.001(X_1*X_2))}\Big)^{1}$$

$$p(MAIS3+F) = \ 1+e^{(-0.460+0.091*X_1+0.039*X_2\ \ 0.119*X_3+0.029*X_4+0.002(X_1*X_2))}\Big)^{1}$$

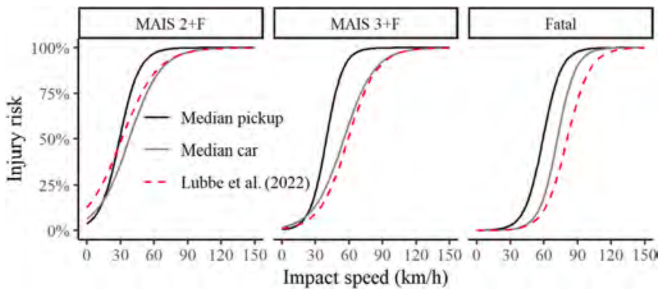


Fig. 3. Pedestrian injury risk curves for MAIS 2+F, MAIS 3+F, and fatal crashes with estimates for the sample's median-height pickup truck (109 cm) and car (75 cm) alongside estimates from Lubbe et al. (2022).

Table 3
Estimated speed (km/h) associated with fatal injury risk at different thresholds alongside estimates from Tefft (2013), with equivalent speeds in mph.

	Tefft (2013)	Current study
Risk (%)	km/h (mph)	km/h (mph)
10	38.8 (24.1)	50.3 (31.3)
25	52.3 (32.5)	59.2 (36.8)
50	65.3 (40.6)	68.0 (42.3)
75	77.2 (48.0)	77.1 (47.9)
90	87.9 (54.6)	85.9 (53.4)

Table 4
Sample mean values from the combined VIPA/VICIS dataset.

	X_1	X_2	X_3	X_4
	Impact speed	HLE height	Sex	Age
$\bar{x}$	42.79	85.25	0.59	42.42

Note. HLE = hood leading edge.

$$p(Fatal) = \ 1+e^{(-3.280+0.123*X_1+0.047*X_2+0.319*X_3+0.030*X_4+0.000(X_1*X_2))}\Big)^{1}$$

For example, the following would calculate the probability of a fatality resulting from a vehicle with a 90 cm high hood leading edge striking a female, 30-year-old pedestrian at 50 km/h:

4. Discussion

The purpose of the current study was to generate modern crash injury risk curves for pedestrians in the United States. Our findings suggest a similar fatality risk curve compared with past estimates from U.S. crash data but a slightly more pronounced relationship between impact speed and injury risk compared with research using European samples, with pedestrians suffering greater injury risk at lower impact speeds. The increased injury risk we observed likely stems from the composition of the U.S. fleet—separating our injury risk estimates by hood leading edge height produced an estimate for a shorter vehicle (e.g., a passenger car) that approximated estimates from GIDAS (Lubbe et al., 2022). Indeed, we found that greater vehicle height was consistently associated with greater injury risk overall and also amplified the risk from faster impact speeds.

Our finding that pedestrian injury outcomes were affected by the construction of the striking vehicle's front end is consistent with past research on vehicle size and shape. Higher vehicle front ends have been linked to greater injury risk and severity (e.g., Hu et al., 2024; Monfort & Mueller, 2020; Monfort et al., 2024; Tyndall 2024). The increased risk and severity of injury from these vehicles is related to their tendency to inflict more severe injuries higher on the body: to the head, torso, and hip (Longhitano et al., 2005; Monfort et al., 2024; Zhang et al., 2008). A pedestrian who is struck higher on the body is also more likely to be thrown forward after the initial impact rather than rolled up the hood, placing them at greater risk of being subsequently run over (Edwards & Leonard, 2022; Roudsari et al., 2005). We found that the injury risk discrepancy between shorter and taller vehicles grows as impact speed increases, which is also consistent with past work (Monfort & Mueller, 2020).

The similarity between our fatal risk curve and that estimated by Tefft (2013) using U.S. pedestrian crash data from 1994 to 1998 was unexpected. Given the growing prevalence of large passenger vehicles on today's roads, pedestrians today should be at greater risk of injury than pedestrians 30 years ago (e.g., IIHS, 2023). The shape of Tefft's (2013) fatality risk curve may be related to his inclusion of relatively more pickup trucks (13% of his sample compared with just 8% of ours; B. Tefft, personal communication, September 4, 2024) as well as large light vehicles excluded from our sample (e.g., 5% cargo vans). The composition of vehicles in crash data used to inform a pedestrian risk curve will strongly determine the shape of that curve. That is, our findings suggest that an explicit modelling of the front-end characteristics of striking vehicles is required to obtain an accurate estimate of pedestrian injury risk.

Taller vehicles may be more likely to be involved in certain pedestrian crash configurations than shorter ones, potentially due to limitations in driver visibility (Hu & Cicchino, 2022). In cases where the pedestrian is at the vehicle's front corner, obstructed driver sight lines to this area could make a collision more likely and may also reduce pre-impact braking behaviour, producing crashes of higher impact speed and greater injury severity. Greater pedestrian crash risk due to poor visibility has consistently been observed in cases involving large trucks (e.g., Cheng et al., 2016; New York City Department of Transportation, 2010; Young et al., 2023); as U.S. passenger vehicles continue to get larger and taller, visibility may become a correspondingly more common contributor to pedestrian crashes. Additional research is needed to more fully understand the risks associated with pedestrian crashes from limited driver visibility.

4.1. Applications and countermeasures

The Safe System approach involves minimizing crash risk through several avenues (Larsson & Tingvall, 2013), including vehicle, infrastructure, and roadway design. Our findings reinforce the importance of designing less aggressive vehicles discussed at length by recent work (e.g., Edwards & Leonard, 2022; Hu et al., 2024; Monfort et al., 2024). However, the implications of our findings also extend to safe roadway design, specifically for reducing vehicle speed in areas where pedestrians and motor vehicles are expected to mix. We found that the threshold for a safe crash speed (the speed associated with a 10% risk of serious injury; Larsson & Tingvall, 2013) occurred at 24 km/h (or approximately 15 mph). Although a common speed limit in residential areas in the United States is 25 mph, the specific limits can vary by state, city, or even neighbourhood, with some areas opting for lower limits depending on local conditions and safety priorities. Our findings suggest that lowering the speed limit to 15 mph in areas with large numbers of pedestrians would significantly improve crash outcomes. Indeed, a study of 40 European cities that implemented a similar speed limit city-wide (30 km/h, or 18.6 mph) observed a significant decrease in crashes, injuries, and fatalities following the change (Yannis & Michelaraki, 2024). If a 24 km/h (15 mph) limit is not feasible, small reductions can still have a large effect on injury outcomes. For example, our data suggest that reducing crash speeds from 50 km/h to 40 km/h (or from about 30 mph to 25 mph) would still cut serious injury risk nearly in half, from 62% to 37%. Research suggests that lower speed limits do reduce travel speeds: when Boston reduced its default speed limit from 30 mph to 25 mph in 2017, instances of vehicles exceeding 25 mph, 30 mph, and 35 mph (40 km/h, 49 km/h, and 56 km/h) reduced by 3%, 9%, and 29%, respectively (Hu & Cicchino, 2020). Where speed limits cannot be reduced, other traffic-calming measures can be implemented, such as installing speed cameras (Wilson et al., 2010), narrowing lanes (Pawlovich et al., 2006), or hardening centerlines (Hu & Cicchino, 2020). In sum, lower speed limits and traffic-calming measures in areas where pedestrians and vehicles are expected to commingle could substantially reduce both the number and severity of pedestrian injuries.

Pedestrian crashworthiness evaluations have recently been proposed for the U.S. New Car Assessment Program (NHTSA, 2023). These evaluations would provide some guidance to automakers with respect to improving the energy absorption of front-end components in pedestrian crashes and would likely improve crash outcomes. However, this guidance would be restricted to individual components testing (e.g., hoods, windshields, A-pillars, etc.) with body-region-specific impactors (e.g., headform and legform), which would not provide a direct incentive to address rising hood leading edge heights. There are currently no regulatory or consumer tests in the United States that incorporate the height of a vehicle's front end and its relationship with pedestrian injury risk. Unfortunately, the greater injury risk that large vehicles pose to pedestrians is an externality that is unlikely to be accounted for by purchasers of those vehicles (Lindberg, 2005). The data are increasingly clear that taller vehicles inflict more severe pedestrian injuries, and so special attention should be paid to developing regulatory and engineering countermeasures for these crash scenarios.

Vehicles equipped with pedestrian AEB systems have the potential to mitigate pedestrian injuries and fatalities through impact speed reduction. These technologies monitor traffic in front of vehicles, warning and intervening with braking if a crash is imminent. A recent assessment of these systems found that vehicles with pedestrian AEB were associated with a 27% lower rate of pedestrian crashes and a 30% lower injury rate than those without the technology (Cicchino, 2022). Similarly, insurance claim rates involving pedestrian injury were 35% lower for Subaru vehicles with optional pedestrian AEB than those without it (Wakeman et al., 2019). A theoretical assessment of U.S. pedestrian crashes suggests that high-performing pedestrian AEB systems could decrease fatalities by 84–87% and MAIS 3+F injuries by 83–87% (Haus et al., 2019). However, research also suggests that these systems are not effective along roads with a speed limit of 80 km/h (50 mph) or higher (Cicchino, 2022), suggesting an upper limit for speed limits along roadways where pedestrians are expected to travel. Changes to hood design may also stand to benefit pedestrians; deployable hoods that lift slightly before impact could help prevent severe head injuries resulting from contact with rigid components in the engine bay (Standroth et al., 2014). In sum, advanced crash avoidance technology stands to benefit pedestrians even if vehicle front-end shape remains unchanged. Consumer evaluation of these systems has drawn attention to the potential they hold for improving safety, promoting their wider incorporation into the fleet (IIHS, 2024b). The updated risk curves presented by the current study can inform decisions on new test scenarios that will increase pedestrian AEB effectiveness even further.

4.2. Limitations

Our crash data consisted of single-vehicle pedestrian crashes in cities around Michigan (VIPA) as well as New Jersey, California, and Texas (VICIS). Each of these four states come from a different U.S. census region (Northeast, South, Midwest, West). These regions represent different geographic, cultural, economic, and demographic characteristics that may affect where and how vehicles are driven and crashed (Farmer et al., 2022). However, our data were not explicitly collected with representativeness in mind (i.e., not stratified by urban or rural specification, road miles travelled, etc.). Given that our data came primarily from urban areas, for example, the resulting injury risk curves might be most accurate for crashes that occur along roads in urban centers. Crashes along rural roads tend to differ slightly from those in urban areas. For example, they tend to involve higher average speed limits, less ambient light, and fewer pedestrian-friendly improvements. Consequently, they also tend to produce more severe pedestrian injuries (Chen & Fan, 2019). To the extent that our data do not represent crashes more common in rural areas, our findings may be limited. Nonetheless, we weighted our regression model to more closely match the injury severity distribution estimated by a representative national sample, and the injury risk curves we have produced fall in line with past work and with our expectations related to the relatively large vehicles present in the U.S. fleet.

5. Conclusion

We estimated pedestrian injury risk curves using modern crash data from the United States. Compared with recent work using European samples, we observed a more pronounced relationship between impact speed and injury risk, with the hood leading edge of the striking vehicle driving differences in injury severity outcomes. Our findings support a reduction of U.S. speed limits in areas where pedestrians and motor vehicles are expected to mix—even a small reduction could dramatically improve pedestrian injury outcomes. More rigorous pedestrian crashworthiness evaluations and the implementation of pedestrian-friendly safety technology (like AEB or deployable hoods) may be important as well.

CRediT authorship contribution statement

Samuel S. Monfort: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Becky C. Mueller:** Writing – review & editing, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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