OPEN ACCESS

Do sports utility vehicles (SUVs) and light truck vehicles (LTVs) cause more severe injuries to pedestrians and cyclists than passenger cars in the case of a crash? A systematic review and meta-analysis

Elsa Robinson,[1] Phil Edwards ,[2] Anthony Laverty ,[3] Anna Goodman [2]

► Additional supplemental material is published online only. To view, please visit the journal online (https://doi.org/10.1136/ip-2024-045613).

[1]Former Student, London School of Hygiene & Tropical Medicine, London, UK
[2]Department of Population Health, London School of Hygiene & Tropical Medicine, London, UK
[3]Imperial College London, London, UK

Correspondence to
Dr Anna Goodman; anna.goodman@lshtm.ac.uk

Received 20 December 2024
Accepted 24 March 2025

ABSTRACT

Questions In the case of a road traffic crash, do sports utility vehicles (SUVs) and light truck vehicles (LTVs) cause more severe injuries to pedestrians and cyclists than passenger cars? Does any effect differ between adults and children?

Design Systematic review and meta-analysis.

Data sources MEDLINE, TRID and Global Index Medicus were searched up to September 2024, with no restrictions by setting or language.

Inclusion criteria Eligible studies had to compare injury severity between pedestrians and/or cyclists hit by an SUV or LTV versus a passenger car. Only sources using real-world crash data were included.

Main outcome measure Injury severity, defined either as 'fatal versus non-fatal injury' or as 'killed or seriously injured (KSI) versus slight injury'.

Results 24 studies were included in the meta-analysis. The results were similar between pedestrians and cyclists. When combining pedestrians and cyclists, the pooled odds of KSI versus slight injury if hit by an SUV/LTV versus a passenger car were higher among adults/all-age samples by 1.24 (95% CI 1.15, 1.34) and higher among children by 1.28 (95% CI 1.19, 1.37). The odds of fatal versus non-fatal injury if hit by an SUV/LTV versus a passenger car increased among adults/all-age samples by 1.44 (95% CI 1.33, 1.56) and among children by 1.82 (95% CI 1.57, 2.11; p=0.006 for heterogeneity by age).

Conclusion In the case of a crash, SUVs and LTVs cause more severe injuries to pedestrians and cyclists than passenger cars. This effect is larger for fatalities than for KSIs, and the fatality effect is particularly large for children.

PROSPERO registration number CRD42024597283.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Sports utility vehicles (SUVs) and light truck vehicles (LTVs) are ever more popular worldwide, with SUVs accounting for over half of new car sales in many high-income countries.

⇒ The most recent synthesis of the road danger impacts of these large vehicles only covered studies published up to 2006 and did not cover impacts on cyclists or on children specifically.

WHAT THIS STUDY ADDS

⇒ Our study found that, in the case of a crash, being hit by an SUV or LTV increased the odds of a pedestrian or cyclist being killed or seriously injured by around a quarter. The odds of a pedestrian or cyclist being killed increased by 44% for adult/all-age samples and increased by 82% for children.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Several cities and countries have introduced or are currently considering policies to discourage use of large vehicles (eg, higher parking charges). Our findings strengthen the road danger rationale for such policies.

INTRODUCTION

Road traffic collisions are an important cause of death and serious injury, with 1.19 million road traffic deaths per year globally.[1] In addition, perceptions of road danger deter people from walking and cycling,[2] leading to a greater reliance on motor vehicles. This creates a vicious circle that may further increase road danger to vulnerable road users, while also increasing physical inactivity and air pollution.

Many countries and cities have developed strategies seeking to reduce road danger using the 'safe system approach', one component of which is a focus on 'safe vehicles'. One concerning trend is the growing popularity around the world of sports utility vehicles (SUVs) and light truck vehicles (LTVs; a category that covers SUVs, smaller vans and pick-up trucks). SUVs and LTVs are taller, wider and heavier than traditional 'passenger cars', such as sedans or hatchbacks. As of 2023, SUVs made up 48% of new car sales globally, up from 15% in 2010.[3]

This trend is of concern given evidence that, in the case of a crash, these larger vehicles may be more dangerous to vulnerable road users. The key mechanism underlying this increased risk appears to be the taller and blunter profile of the front end of SUVs and LTVs. This means that the victim is initially struck higher up on their body (eg, the pelvis not the legs for an adult, or the thorax not the pelvis for a child). It further means that the victim is more likely to be thrown forward into the road, rather than carried on the vehicle's hood. These and other crash dynamics are associated with a

To cite: Robinson E, Edwards P, Laverty A, *et al*. *Inj Prev* Epub ahead of print: [*please include* Day Month Year]. doi:10.1136/ip-2024-045613

higher proportion of upper body injuries (including to the head, thorax and abdomen) and with a more serious injury profile.[4–9] A large recent study in the USA found that, as compared with the low and sloping front end of a traditional passenger car, the odds of pedestrian fatality increased by 45% if the striking vehicle had a tall and sloped front end; increased by 44% if the striking vehicle had a tall and blunt front end; and increased by 26% if the striking vehicle had a medium-height and blunt front end.[7]

Much of this evidence comes from the USA, where vehicle standards to mitigate crashes and protect pedestrians are currently weaker than those in Europe. Nevertheless, recent studies in both settings have yielded similar findings regarding the adverse effects of higher front ends: a 10 cm increase in front-end height was associated with a 22% increase in the odds of fatality for pedestrians in the USA[10] and a 27% increase in the odds of fatality for vulnerable road users (pedestrians, cyclists and motorcyclists) in Belgium.[11] This provides suggestive evidence that despite plausible variation in absolute risk levels, higher vehicle front ends may increase relative risk in both settings.

Consistent with the above findings, a previous systematic review found that LTVs increase the odds of pedestrian injury by 54% compared with passenger cars (OR 1.54; 95% CI 1.15, 1.93).[12] This review only covered studies published up to 2006, however, and did not cover impacts on cyclists or on children specifically. A specific focus on children is warranted given that children are shorter and are therefore expected to be particularly at risk if hit by a vehicle with a tall front end.[13] For instance, the above-mentioned US study found that a 10 cm increase in front-end height increased the odds of death by 21% for adult pedestrians and by 81% for child pedestrians.[10]

The present study therefore seeks to update the previous review by synthesising available evidence as to whether, in the case of a crash, SUVs and LTVs cause more severe injury to pedestrians and cyclists than passenger cars. We also examine whether any effect differs between children and adults.

METHODS

Search strategy

Three electronic databases were searched: MEDLINE (Ovid) (https://ovidsp.ovid.com/), TRID (https://trid.trb.org/) and Global Index Medicus (https://www.globalindexmedicus.net/). The search was conducted on 6 September 2024, with no limitations by date or language of publication. Our PECO criteria were as follows:

- Population: pedestrians and/or cyclists of all ages hit by a motor vehicle.
- Exposure: collision with an SUV or LTV.
- Control: collision with a passenger car.
- Outcome: injury severity, dichotomised either as 'fatal/non-fatal' or as 'killed and seriously injured (KSI)/slight'.

See online supplemental appendix 1 for further details, including our search strings.

Inclusion criteria

Our inclusion criteria are described in detail in online supplemental appendix 1. Briefly, studies eligible for inclusion were those comparing SUVs or LTVs with passenger cars in relation to injury severity in pedestrians or cyclists. All pedestrian and cyclist ages, driving locations, countries and time periods were included. Only studies using real-world, individual-level crash data were eligible. Studies using crash reconstructions and computer simulations were excluded, as were ecological studies. The outcome had to be a dichotomous, global measure of injury severity, as opposed to, for example, the body region injured.

Eligible studies needed to provide individual-level data that could be used to calculate or approximate an OR and its SE. We excluded studies that adjusted for variables that were potentially on the causal pathway between vehicle type and injury severity (eg, vehicle weight). We included studies that adjusted for confounders that did not plausibly lie on the causal pathway, such as victim and driver demographic characteristics, crash location and weather conditions.

Unlike a previous systematic review,[12] we did not consider studies of driveway roll-over crashes eligible for our main meta-analysis. Driveway roll-over crashes capture incidents where, for example, the driver reverses their vehicle over a child playing in the driveway. We consider this a qualitatively different type of incident compared with an on-road traffic crash. We do, however, describe the findings of these driveway roll-over crash studies in online supplemental appendix 6.

Screening and selection

The title and abstract of each study were assessed against the inclusion criteria by two reviewers independently. Papers that either reviewer considered to be eligible were downloaded for a full-text review against the same criteria. This was again done independently by two reviewers, with uncertainties decided in discussion with a third reviewer.

The reference lists of all sources eligible for inclusion were also checked for other relevant papers.

Data extraction and preparation

Data were independently extracted by two reviewers using a standard template. For each study, we recorded whether the exposure comparison was 'SUV versus passenger car' or 'LTV versus passenger car'. We also recorded crash victims' age group(s) (child, adult or an 'all-age' sample containing both children and adults) and travel mode (pedestrians, cyclists or a combined sample containing pedestrians and cyclists).

For our main meta-analysis, the a priori primary outcomes used were the ORs for (1) fatal (versus non-fatal injury) or (2) KSI (versus slight injury). Where both KSI and fatality ORs were available from a single study, we extracted both. Where a study did not present either of our primary outcomes but did include a different dichotomous measure of injury severity, we extracted this for a sensitivity analysis (n=1 study).

Where a study included data that allowed both SUVs and LTVs to be contrasted with passenger cars, we extracted both, for the purpose of comparison. We ultimately used the SUV versus passenger car contrasts in the main meta-analysis.

Where both crude and adjusted ORs were available from a single study, we extracted both for the purpose of comparison. We used the adjusted OR in our main meta-analysis.

For each included study, we additionally sought to extract information on the setting and date of the crashes studied, whether crashes were identified retrospectively or prospectively, the location of crashes (eg, 'any location' versus 'driveway studies only'), the source of crash data (eg, police, hospital, insurance data) and the crash victim sample size.

We contacted the study authors if relevant information was not presented or was unclear in the published papers. See online supplemental appendix 2 for a log of author-supplied data used in this study).

We contacted the study authors if relevant information was not presented or was unclear in the published papers. See online

supplemental appendix 2 for a log of author-supplied data used in this study).

Risk of bias assessment

The studies were assessed by one reviewer using the ROBINS-E (Risk Of Bias In Non-randomized Studies of Exposures) tool. This tool provides a framework for assessing the potential for bias in observational epidemiological studies. An assessment is made against seven domains, which allows for judgement regarding the risk of bias, the predicted direction of bias and whether the risk of bias is sufficiently high to threaten the conclusions of the study.

Statistical analysis

Where there was a 0 in the 2×2 table for any study, 1 was added to each cell of that table before the meta-analysis was performed (n=1 study). Where ordinal logistic regression was used, that 'beta' value was used to approximate the OR for a KSI versus slight comparison (n=2 studies). (Note that the assumption underlying ordinal logistic regression is that one achieves the same beta regardless of where one 'cuts' the data. Thus, in theory, the beta should capture the 'fatal' versus 'non-fatal' contrast just as well as it captures the 'KSI' versus 'slight' contrast. In practice, however, the smaller number of fatal injuries relative to serious and slight injuries means that we expected the approximation to be closer for the 'KSI' versus 'slight' contrast. We confirmed that our findings for KSIs were very similar in the sensitivity analysis excluding these two studies.) Where multiple ORs were presented stratified by factors irrelevant to our research question, fixed-effect meta-analysis was used to generate a single pooled estimate (n=1 study). Where weighted estimates were generated, we used the weighted data to generate the OR and the unweighted data to generate the SE (n=2 studies).

Pooled ORs and 95% CIs were then estimated and corresponding forest plots were generated using a random-effects meta-analysis of the log odds. Tests for between-group heterogeneity were performed using Cochran's Q statistics for heterogeneity. We created a funnel plot and performed an Egger test to test for small-study effects (reporting bias). Our analyses used the STATA/SE V.14.0 software.

Indicative estimates of population impact

Our focus in this meta-analysis is on ORs, that is, an epidemiological measure of the *effect* of SUVs and LTVs. Also of interest is their *impact* at the population level. Impact depends both on the strength of the effect and also on the prevalence of the exposure—that is, what proportion of car crashes involve larger vehicles. One measure of impact is the population attributable fraction (PAF), which estimates the proportion of pedestrian and cyclist car crash injuries that would be averted if all SUVs were replaced with passenger cars. We focused on SUVs here because we consider it plausible that, in principle, most trips by SUVs could indeed reasonably instead be made by passenger cars. By contrast, trips by pick-up trucks and vans are expected more often to involve transporting goods in a way that could not readily be achieved using a passenger car.

We calculated the PAF using the following formula:

$$PAF = (P * (OR - 1)) / (1 + P * (OR - 1))$$

where OR is the odds ratio and P is the prevalence (ie, the proportion of car crashes that involve SUVs). For the OR in this equation, we used the pooled OR from our meta-analyses. The prevalence is expected to vary between settings and to have increased in recent years, given that larger vehicles have been growing rapidly as a share of the fleet. For the prevalence, we therefore present a range of estimates.

Additional and sensitivity analyses

We determined a priori initially to stratify by age (adult/all-age versus children) and by victim mode (pedestrians versus cyclists). Most studies only had a single 'child' age group (with an upper age limit ranging from 13 to 19 years), but where data were available we also contrasted younger versus older children.

We tested for heterogeneity by exposure (SUV versus LTV) and by outcome (fatal versus KSI) and decided whether to stratify by these characteristics based on the empirical results. We further examined whether there was evidence of heterogeneity by study setting. Comparisons of crude versus adjusted effects, where available, informed our interpretation of the potential impact of confounding on our results.

Further sensitivity analyses tested for the impact on the effect estimates of excluding 10 studies that brought modest duplication, of including one study that used an alternative threshold to categorise injury severity, and of restricting our analyses to studies that collected data since 2010.

RESULTS

Description of studies

We identified 1936 studies, of which 205 were screened at the full-text stage. A total of 24 studies were included in our systematic review and main meta-analysis (figure 1). In addition, a further five studies were used in the sensitivity analysis (see online supplemental appendix 5), and a further three studies covered driveway crashes only, and we describe them separately (see online supplemental appendix 6).

The 24 studies used in the main meta-analysis yielded a total of 55 contrasts comparing SUVs or LTVs with passenger cars in road traffic crashes (table 1). Note that one study can yield more than one contrast if, for example, it includes results for both pedestrians and cyclists (see online supplemental appendix 3 for details of the 24 studies individually).[8 9 14–35] Most of the evidence we found came from the USA (44 out of 55 contrasts), and most of our contrasts involved crude rather than adjusted data (48 out of 55 contrasts). We also found more evidence in relation to pedestrians than cyclists (34 versus 16 contrasts) and in relation to adults/all-age samples than to children (41 versus 14 contrasts).

Across 23 studies that reported raw numbers, 21% of victims had KSI injuries versus 79% slight injuries, and 3% of victims had fatal injuries versus 97% non-fatal injuries. Given that ORs only approximate risk ratios for rare outcomes, we expect the pooled ORs presented below in Table 2 to somewhat overestimate the underlying risk ratios for KSI injury, but to approximate the risk ratios for fatality fairly well.

Methodological quality of included studies

Missing data, measurement bias and selection bias

22 of the 24 studies used in the main meta-analysis used established police, hospital or trauma databases. Data were collected by researchers at the collision site in only two studies,[31 33] contributing 0.1% of the total sample. These established databases may suffer from missing data or measurement error (eg, misclassifying a 'slight' injury as 'severe'), but there is no reason to believe that this would apply differentially according to the striking car type.

These established databases are also expected to miss some crash victims, particularly those sustaining slight injuries.[36] For

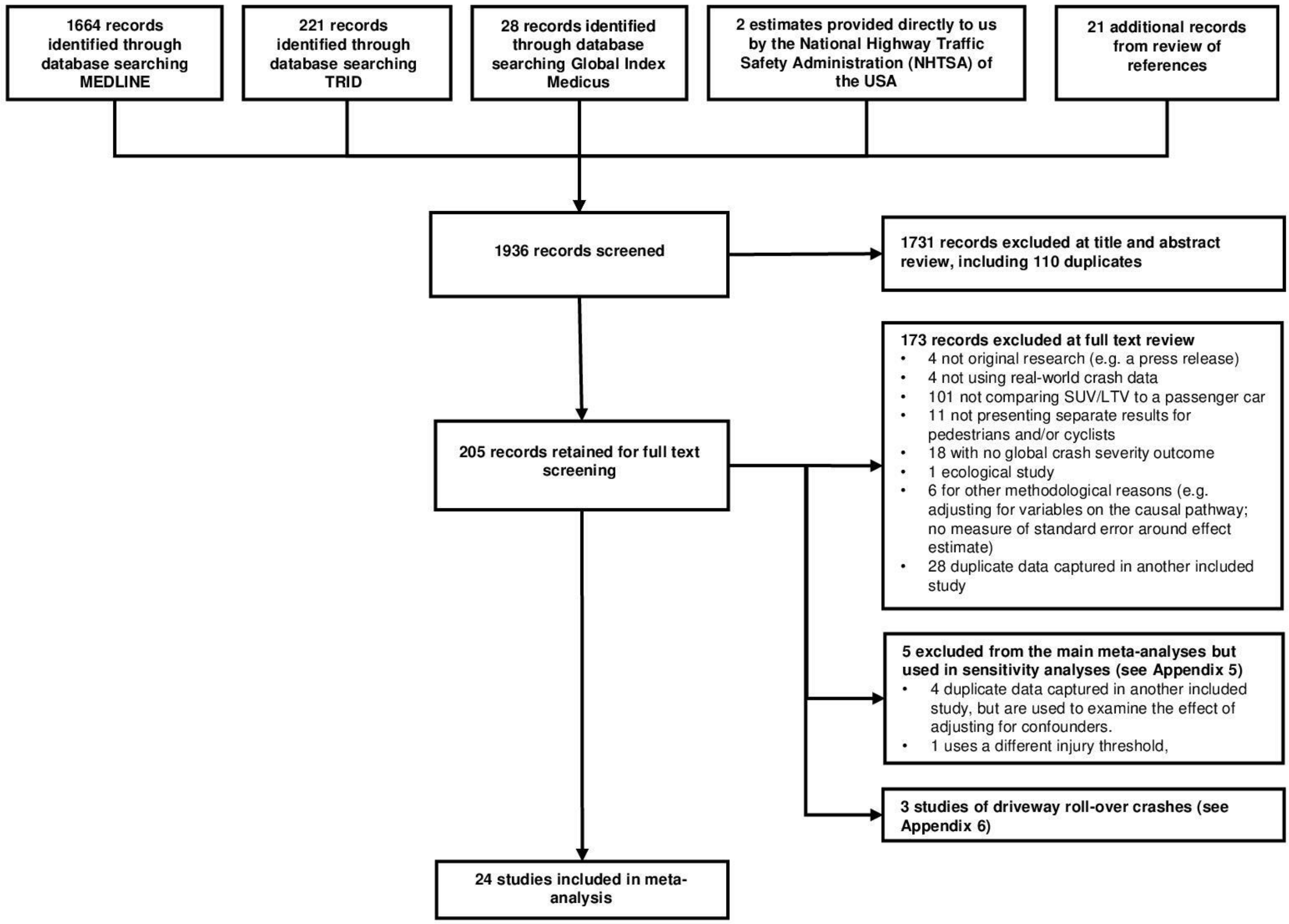

Figure 1 Flow diagram describing the process of study selection. LTV, light truck vehicle; SUV, sports utility vehicle.

a given level of injury severity, there is no reason to expect that the proportion of injuries missed would differ according to the striking car type—that is, a 'slight' injury is expected to be equally likely to be captured regardless of whether the striking car was an SUV or LTV versus a passenger car. We therefore do not expect the effect sizes from our studies to be subject to substantial selection bias. However, insofar as passenger cars are associated with slighter injuries, these routine data sets are likely to be missing a higher share of all passenger car injuries than SUV or LTV injuries. This truncation of the distribution would be expected to underestimate to a modest degree the true association between vehicle type and injury severity.

Reporting bias

We found no evidence of publication bias when comparing the effect size of each contrast with its precision (p=0.11 in an Egger test for small-study effects) (see online supplemental appendix 4 for more details).

Testing for heterogeneity by exposure, outcome and analysis method

We found no evidence of heterogeneity between studies where the exposure was 'SUVs' as opposed to 'LTVs' (see online supplemental appendix 4). We therefore decided to combine these exposure categories throughout our analyses. We present a sensitivity analysis restricted to SUV studies only in online supplemental appendix 5.

We found strong evidence of heterogeneity according to whether the outcome was KSI/slight as opposed to fatal/non-fatal (see online supplemental appendix 4), and we therefore stratify our analyses by outcome type.

We found no convincing evidence of heterogeneity by setting (USA vs Europe vs elsewhere), although the relatively small number of non-USA studies meant that this contrast was not well powered, and some results were ambiguous (see online supplemental appendix 4).

online supplemental appendix 4).

We found no convincing evidence of heterogeneity by setting (USA vs Europe vs elsewhere), although the relatively small number of non-USA studies meant that this contrast was not well powered, and some results were ambiguous (see online supplemental appendix 4).

Lastly, we compared crude versus adjusted results from the 10 contrasts (seven studies) where both were available (see online supplemental appendix 4).[10 16 31 32 37–39] This included four studies that did not feature in our main meta-analysis, because of data duplication, but that did contribute useful information in relation to the effect of adjusting for potential confounders (see figure 1). We found that adjustment generally had only a modest effect, and that any effect was consistently in the direction of increasing the effect estimate. This suggests that the estimates generated by the present meta-analysis, which largely relied on crude data (table 1), are not likely to be subject to major confounding. To the extent to which confounding is present,

Table 1 Descriptive characteristics of the 55 contrasts, from 24 studies, that covered 'all location' crashes and that are included in our main analysis

		Contrasts (studies), n
Country	Australia	2 (1)
	Canada	2 (1)
	China	1 (1)
	France	1 (1)
	Germany	2 (1)
	The Netherlands	1 (1)
	South Korea	1 (1)
	United Arab Emirates	1 (1)
	USA	44 (16)
Striking vehicle (as compared with passenger car)	SUV	41 (17)
	LTV	14 (7)
Injury outcome	KSI versus slight*	28 (17)
	Fatal versus non-fatal	27 (16)
Crash victim	Pedestrian	34 (20)
	Cyclist	16 (8)
	Pedestrian+cyclist pooled	5 (2)
Victim age	Child	14 (6)
	Adult	20 (8)
	All ages	21 (15)
Crude/adjusted	Crude: raw numbers	48 (20)
	Adjusted	7 (5)

Note that the number of studies can add to more than 24 across categories, as one study can provide more than one type of contrast (eg, for both children and adults and/or for both pedestrians and cyclists and/or for both KSI/slight and fatal/non-fatal injuries) See online supplemental appendix 3 for details of the 24 studies individually.
*This includes two contrasts (two studies) in which KSI versus slight is approximated based on the results of an ordered logistic regression across levels of injury severity.
KSI, killed and seriously injured; LTV, light truck vehicle; SUV, sports utility vehicle.

it is likely that our crude estimates are conservative, underestimating the causal effect of being hit by an SUV or LTV versus a passenger car.

Main results

The findings of our meta-analysis are shown in table 2, based on 24 studies and a combined sample size of 682 509 crash victims. In all 12 analyses shown in table 2, there was very strong evidence ($p<0.001$) that the pooled estimate was greater than 1—that is, that, in the case of a crash, pedestrians and cyclists experienced more severe injuries if hit by an SUV or LTV than if hit by a passenger car. The results for pedestrians and cyclists were relatively similar, with no evidence of heterogeneity ($p>0.05$ for heterogeneity by victim mode for all four age bands×outcome groups).

For pedestrians and cyclists combined, the odds of suffering KSI injury when hit by an SUV or LTV as opposed to a passenger car were 24% higher in adults and 28% higher in children, with no evidence of a difference by age band. These results are illustrated in figure 2.

For pedestrians and cyclists combined, the odds of fatality when hit by an SUV or LTV as opposed to a passenger car are 44% higher for adult/all-age samples and 82% higher for children. These results are illustrated in figure 3. This difference between adult/all-age versus child samples was highly statistically significant for pedestrians and when combining pedestrian and cyclist studies (both $p\leq0.006$ for heterogeneity). For cyclists, the number of studies was smaller and the difference between adult/all-age and child samples was not statistically significant ($p=0.35$ for heterogeneity), but there was again a trend for a higher OR in children (1.54 vs 1.26 in adults).

We further explored this age difference in the odds of fatality by comparing the results, where available, between younger versus older children. This contrast was only available from two of the studies in our meta-analysis, namely the two large, nationally representative data sets gathered by the US National Highway Traffic Safety Administration (NHTSA; covering the years 1994–2015[34] and 2016–2022[35]). As described more fully in online supplemental appendix 3, child pedestrians and cyclists aged 0–9 years in these studies experienced a 48% increase in the odds of KSI (pooled OR 1.48; 95% CI 1.34, 1.63) and a 130% increase in the odds of fatality (pooled OR 2.30; 95% CI 2.09, 2.53) if hit by an SUV versus passenger car—that is, even larger than the increases observed for children as a whole.

All the findings presented in table 2 were very similar in the sensitivity analyses excluding 10 US studies whose sample partly overlaps with the sample captured in the NHTSA data,[8 15–17 21 24 30 31 40 41] or additionally including a further one contrast that dichotomised injury severity using a lower threshold than 'severe'.[42] Our findings were also similar in the analyses restricted to studies with a midpoint data collection year of 2010 or later, and in the analyses restricted to studies that compared SUVs with passenger cars. See online supplemental appendix 5 for further details.

Table 2 Pooled OR (95% CI) from random-effects meta-analysis examining the impact of being hit by an SUV or LTV versus a passenger car on injury severity

Victim mode	Outcome	OR (95% CI) (studies)		P value for heterogeneity by age group
		Adult/all-age sample	Children	
Pedestrians	KSI versus slight injury	1.28 (1.13, 1.44) (n=13)	1.34 (1.23, 1.45) (n=3)	0.53
	Fatal versus non-fatal injury	1.42 (1.31, 1.54) (n=13)	1.93 (1.80, 2.06) (n=5)	<0.001
Cyclists	KSI versus slight injury	1.19 (1.07, 1.33) (n=7)	1.19 (1.08, 1.31) (n=2)	0.99
	Fatal versus non-fatal injury	1.26 (1.08, 1.48) (n=5)	1.54 (1.05, 2.25) (n=2)	0.35
Pedestrians and cyclists	KSI versus slight injury	1.24 (1.15, 1.34) (n=17)	1.28 (1.19, 1.37) (n=4)	0.60
	Fatal versus non-fatal injury	1.44 (1.33, 1.56) (n=15)	1.82 (1.57, 2.11) (n=6)	0.006

Note that the final 'pedestrians or cyclists' category includes all studies that examined pedestrians and cyclists separately, plus a further two studies that had pooled pedestrians and cyclists together in the original study. In total, these analyses contain information related to 682 509 crash victims (unweighted).
KSI, killed or seriously injured; LTV, light truck vehicle; SUV, sports utility vehicle.

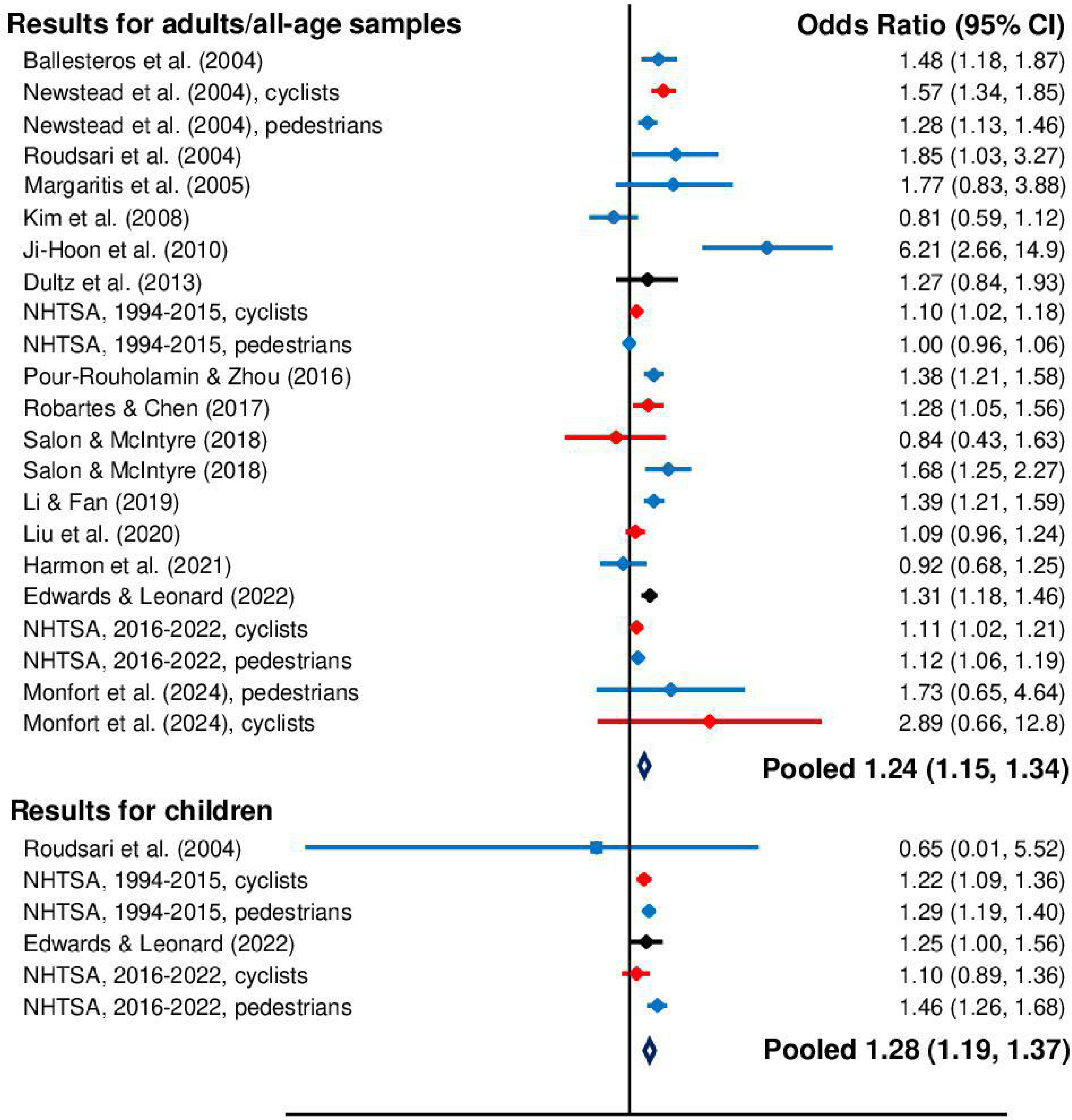

Figure 2 Forest plot of studies examining the odds of KSI versus slight injury for pedestrians and cyclists if hit by an SUV or LTV versus a passenger car. Blue: pedestrians; red: cyclists; black: pedestrians and cyclists combined. KSI, killed or seriously injured; LTV, light truck vehicle; NHTSA, National Highway Traffic Safety Administration; SUV, sports utility vehicle.

Indicative population impacts

Indicative estimates of the population impact of SUVs are provided in table 3. These are estimated by combining the ORs shown in table 2 with estimates of the proportion of car crashes involving an SUV in different settings. In the USA, we estimate that the proportion of SUVs is currently approximately 45%. In Europe, the current proportion is not known and will vary between countries; however, we believe 20% is a reasonable first approximation (see online supplemental appendix 3 for more details).

We estimate that, at present, around 10% of pedestrian and cyclist KSIs from car crashes in the USA would be averted if all SUVs were replaced with passenger cars. There were an average of 17 027 pedestrian and cyclist KSIs per year involving passenger cars or SUVs in the USA between 2016 and 2022.[35] This proportion of 10% therefore translates into around 1700 pedestrian and cyclist KSIs that we estimate would be averted each year if all SUVs in the USA were replaced with passenger cars. For fatalities, the proportion that would be averted is 17%

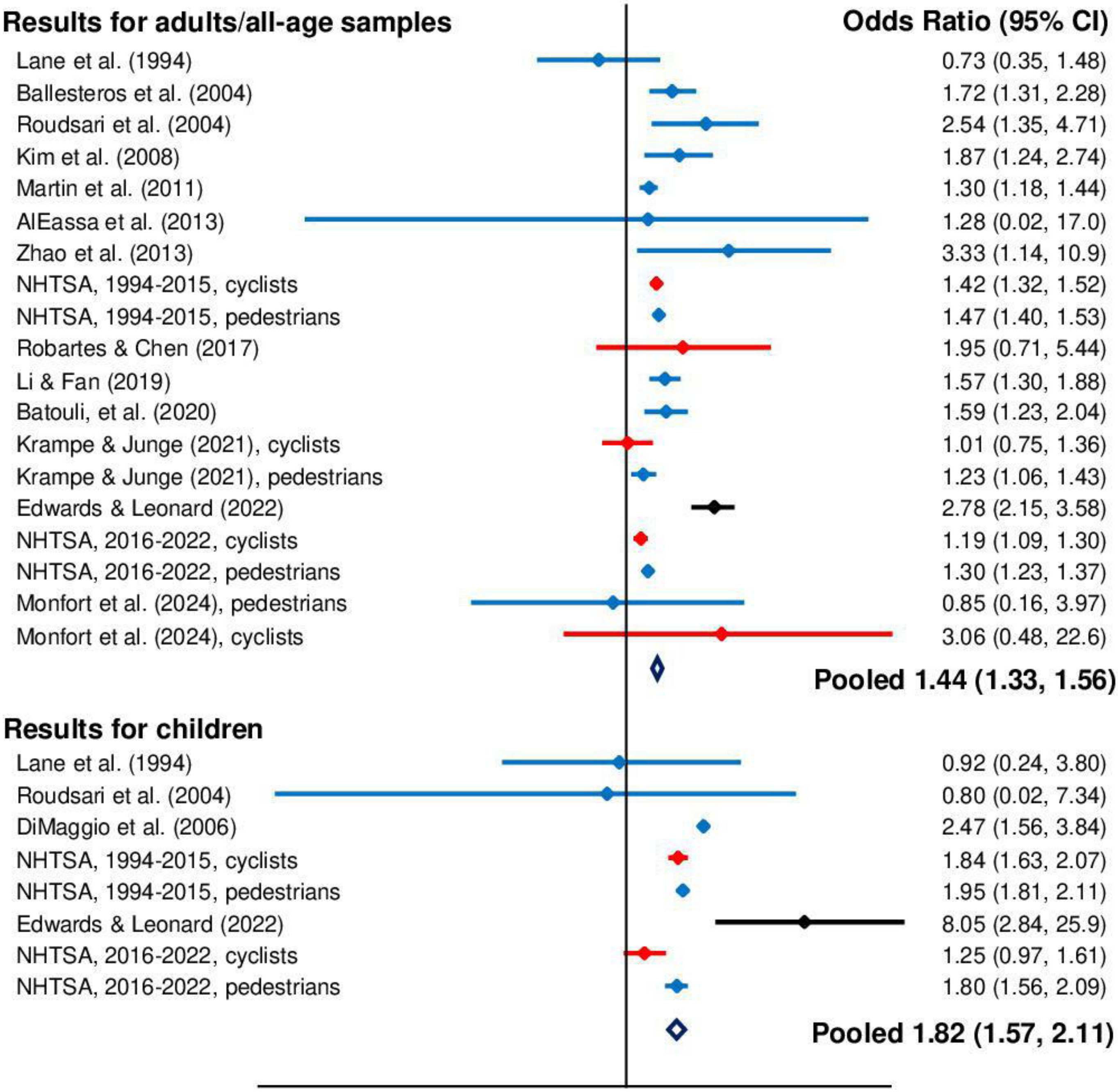

Figure 3 Forest plot of studies examining the odds of fatal versus non-fatal injury, if hit by an SUV or LTV versus a passenger car, for pedestrians and cyclists pooled. Blue: pedestrians; red: cyclists; black: pedestrians and cyclists combined. LTV, light truck vehicle; NHTSA, National Highway Traffic Safety Administration; SUV, sports utility vehicle.

for adults (or around 620 deaths per year) and 27% for children (or around 60 deaths per year).

In Europe, the estimates are expected to be lower, corresponding to the smaller share of SUVs in the vehicle fleet. Based on our estimate of a 20% prevalence of SUVs in car crashes, we estimate the PAFs in Europe to be roughly a magnitude of 5% for KSIs, 8% for adult fatalities and 14% for child fatalities.

DISCUSSION

Main findings

In the case of a crash, a pedestrian or cyclist hit by an SUV or LTV is more likely to be severely injured or killed than a pedestrian or cyclist hit by a passenger car. The size of this effect is similar between SUVs and LTVs as striking vehicles, and similar between pedestrians and cyclists as victims. The odds of being 'killed or seriously injured' increase by about a quarter if hit by an SUV or LTV, for both child and adult pedestrians and cyclists. The odds of being killed increase by 44% for an adult if hit by an SUV or LTV as compared with a passenger car, and by 82% for a child pedestrian or cyclist if hit by an SUV or LTV. The available data further indicate that the effect may be even larger for younger children (aged 0–9 years). The greater fatality risk to children, especially young children, is in line with evidence that a taller front end is one key mechanism because children are shorter.

Table 3 PAF for the proportion of pedestrian and cyclist injuries from car crashes that would be averted if all SUVs were replaced with passenger cars: estimates for the USA and indicative estimates for Europe

Victim mode	Outcome	Adult/all-age sample	Children
Pedestrians	KSI versus slight injury	11% USA ≈5% Europe	13% USA ≈6% Europe
	Fatal versus non-fatal injury	16% USA ≈8% Europe	30% USA ≈16% Europe
Cyclists	KSI versus slight injury	8% USA ≈4% Europe	8% USA ≈4% Europe
	Fatal versus non-fatal injury	10% USA ≈5% Europe	20% USA ≈10% Europe
Pedestrians and cyclists	KSI versus slight injury	10% USA ≈5% Europe	11% USA ≈5% Europe
	Fatal versus non-fatal injury	17% USA ≈8% Europe	27% USA ≈14% Europe

Population attributable fraction (PAF) was calculated using the following formula: PAF = (P * (OR – 1)) / (1 + P * (OR – 1)), where OR is odds ratio and P is prevalence. The ORs were those shown in table 2, and the prevalence of SUVs was estimated to be 45% in the USA and 20% in Europe (see online supplemental appendix 3 for more details).
KSI, killed or seriously injured; SUVs, sports utility vehicles.

Strengths and limitations of this review and directions for further research

This systematic review included 24 studies of all-location crashes, covering 682 509 pedestrian and cyclist casualties occurring between the late 1980s to 2022 (online supplemental table A3.1). One limitation is that most of the evidence (44 out of 55 contrasts) came from the USA, with almost all the remainder coming from other high-income countries. Despite the proliferation of SUV sales around the world,[3] and despite the large burden of road traffic crashes in poorer countries,[1] we found no studies from low-income settings and only one from a middle-income setting (China). Further studies from outside the USA, including low-income and middle-income countries, would be valuable to examine the generalisability of the effects found in this review. We also note that our estimates of population impact in the USA are not expected to generalise to other settings and that our estimates of population impact in Europe are only indicative.

A strength is that most studies were similar in design, collecting data retrospectively from official databases, and in general we judge them at low risk of measurement bias or selection bias. One exception is that routine databases are expected disproportionately to miss slighter injuries. This truncation of the distribution may have introduced a modest conservative bias, underestimating the true association between vehicle size and injury severity. A further limitation is that most studies did not adjust for confounders, and the remainder included an inconsistent mixture of adjustment variables. This is likely to have introduced heterogeneity and means our effect estimates may be subject to confounding. Reassuringly, however, empirical comparisons between crude and adjusted estimates indicated that the degree of confounding was modest, and if anything is likely to have led to our effect estimates being conservative.

A further likely source of heterogeneity in our estimates stems from variation in how different data sources defined 'KSI' as an outcome or defined 'SUV' or 'LTV' as an exposure. There exists no legal international definition of what counts as an 'SUV', and most included studies did not offer any explanation of how they defined this category. We recognise that vehicles classed as SUVs vary in size and shape, and that our use of binary categories is somewhat artificial. In particular, the key underlying road danger mechanism appears to be higher and blunter vehicle front ends,[7 9 10] which cause victims more often to be thrown forward rather than carried and which are associated with more severe injuries to the upper body.[4–6] Front-end profiles vary between SUVs and passenger cars, but they also vary among SUVs. Policies seeking to discourage use of larger vehicles or seeking to make them safer should be mindful of such variation and should ideally target any interventions not according to a label like 'SUV' but instead according to the underlying road danger mechanisms.

A final important limitation of our review is that it only examines the risk to pedestrians and cyclists *in the event of a crash* ('secondary safety') and does not consider the likelihood of a crash occurring in the first place ('primary safety'). Studies examining both primary and secondary safety appear to be scarce, and those studies we know of are based on ecological rather than individual-level designs. Specifically, three ecological US studies found that increased LTV use is associated with increased overall injury rates among vulnerable road users,[43–45] but one ecological New Zealand study found that the KSI rate (to all road users) was similar for SUVs compared with other types of cars.[46] Further evidence on this point would be valuable, ideally collected at the individual level.

Implications for policy

In response to the proliferation of larger vehicles, a number of countries and cities around the world have introduced or are considering policies to discourage use of larger cars. For instance, Paris tripled its parking charges for heavier cars in 2024, and a number of other North American and European cities have introduced or are considering similar measures.[47] Such policies are typically justified with regard to a number of harms from larger vehicles, including greater road danger, higher carbon and air pollution emissions, taking up more parking space and crowding out other road users.

The findings of this review strengthen the road danger rationale for such policies. We would welcome further research into how policies can be most effectively designed, including in terms of capturing the underlying road danger mechanisms. At present, overall height appears promising in this regard, as a widely available vehicle dimension that discriminates well between SUVs and passenger cars, and that is highly correlated with vehicle front-end height.[47]

The findings of this review also highlight the importance of parallel industry efforts to improve the safety of larger vehicles for vulnerable road users, with such efforts again ideally informed by an understanding of the underlying road danger mechanisms. Relevant measures might include improvements in vehicle design, such as improved sightlines, pedestrian automatic emergency braking or designing bumpers and hoods from materials that reduce injury severity. Such 'safer vehicle' improvements should ideally be complemented by policies promoting other elements of the 'safe system approach', including safer infrastructure, safer speeds and safer behaviours.

Acknowledgements We are very grateful to Lukas Hamilton Shanahan and Liam Hamilton Shanahan for their work downloading the PDFs for full-text inclusion; to Ben Armstrong for advice on statistical methods; and to the NHSTA staff for generating bespoke data tables for us.

Contributors ER and AG conceived the studies. All authors contributed to abstract screening and data extraction. ER and AG conducted the analysis and wrote the article, with critical input from PE and AL. AG is the guarantor.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request. Extracted data and analytical code are available on request from the corresponding author.

Supplemental material This content has been supplied by the author(s). It has not been vetted by BMJ Publishing Group Limited (BMJ) and may not have been peer-reviewed. Any opinions or recommendations discussed are solely those of the author(s) and are not endorsed by BMJ. BMJ disclaims all liability and responsibility arising from any reliance placed on the content. Where the content includes any translated material, BMJ does not warrant the accuracy and reliability of the translations (including but not limited to local regulations, clinical guidelines, terminology, drug names and drug dosages), and is not responsible for any error and/or omissions arising from translation and adaptation or otherwise.

ORCID iDs
Phil Edwards http://orcid.org/0000-0003-4431-8822
Anthony Laverty http://orcid.org/0000-0003-1318-8439
Anna Goodman http://orcid.org/0000-0001-9995-6659

REFERENCES

1 World Health Organisation. Global status report on road safety 2023. Geneva World Health Organization; 2023. Available: https://www.who.int/teams/social-determinants-of-health/safety-and-mobility/global-status-report-on-road-safety-2023 [accessed 19 Nov 2024]
2 Department for Transport. National travel attitudes study: wave 5. 2021. Available: https://www.gov.uk/government/statistics/national-travel-attitudes-study-wave-5 [Accessed 19 Nov 2024].
3 IEA. SUVs are setting new sales records each year – and so are their emissions. Paris, 2024. Available: https://www.iea.org/commentaries/suvs-are-setting-new-sales-records-each-year-and-so-are-their-emissions [accessed 19 Nov 2024]
4 Roudsari BS, Mock CN, Kaufman R. An evaluation of the association between vehicle type and the source and severity of pedestrian injuries. *Traffic Inj Prev* 2005;6:185–92.
5 Li G, Wang F, Otte D, *et al*. Have pedestrian subsystem tests improved passenger car front shape? *Accident Analysis & Prevention* 2018;115:143–50.
6 Yin S, Li J, Xu J. Exploring the mechanisms of vehicle front-end shape on pedestrian head injuries caused by ground impact. *Accid Anal Prev* 2017;106:285–96.
7 Hu W, Monfort SS, Cicchino JB. The association between passenger-vehicle front-end profiles and pedestrian injury severity in motor vehicle crashes. *J Safety Res* 2024;90:115–27.
8 Edwards M, Leonard D. Effects of large vehicles on pedestrian and pedalcyclist injury severity. *J Safety Res* 2022;82:275–82.
9 Monfort SS, Hu W, Mueller BC. Vehicle front-end geometry and in-depth pedestrian injury outcomes. *Traffic Inj Prev* 2024;25:631–9.
10 Tyndall J. The effect of front-end vehicle height on pedestrian death risk. *Economics of Transportation* 2024;37:100342.
11 Nuyttens N, Ben Messaoud Y. Impact des caractéristiques des véhicules sur la gravité des lésions des occupants de voiture et de la partie adverse. Bruxelles institut Vias; 2023.
12 Desapriya E, Subzwari S, Sasges D, *et al*. Do light truck vehicles (LTV) impose greater risk of pedestrian injury than passenger cars? A meta-analysis and systematic review. *Traffic Inj Prev* 2010;11:48–56.
13 Ivarsson BJ, Crandall JR, Burke C, *et al*. Pedestrian head impact - what determines thelikelihood and wrap around distance? 2007.
14 AlEassa EM, Eid HO, Abu-Zidan FM. Effects of Vehicle Size on Pedestrian Injury Pattern and Severity: Prospective Study. *World j surg* 2013;37:136–40.
15 Ballesteros MF, Dischinger PC, Langenberg P. Pedestrian injuries and vehicle type in Maryland, 1995–1999. *Accident Analysis & Prevention* 2004;36:73–81.
16 Batouli G, Guo M, Janson B, *et al*. Analysis of pedestrian-vehicle crash injury severity factors in Colorado 2006–2016. *Accident Analysis & Prevention* 2020;148:105782.
17 DiMaggio C, Durkin M, Richardson LD. The association of light trucks and vans with paediatric pedestrian deaths. *Int J Inj Contr Saf Promot* 2006;13:95–9.
18 Dultz LA, Foltin G, Simon R, *et al*. Vulnerable roadway users struck by motor vehicles at the center of the safest, large US city. *J Trauma Acute Care Surg* 2013;74:1138–45.
19 Harmon KJ, Peticolas K, Redding EM, *et al*. Examining the Effect of Pedestrian Crashes on Vulnerable Populations in North Carolina. *N C Med J* 2021;82:237–43.
20 Ji-Hoon KIM, Sun-Pyo KIM, Seong-Jung KIM, *et al*. Analysis of the Factors that Influence the Severity of Injury of Pedestrian Traffic Accident Patients in an Emergency Department. *Journal of the Korean Society of Emergency Medicine* 2010;561–8.
21 Kim J-K, Ulfarsson GF, Shankar VN, *et al*. Age and pedestrian injury severity in motor-vehicle crashes: A heteroskedastic logit analysis. *Accident Analysis & Prevention* 2008;40:1695–702.
22 Krampe J, Junge M. Deriving functional safety (ISO 26262) S-parameters for vulnerable road users from national crash data. *Accident Analysis & Prevention* 2021;150:105884.
23 Lane PL, McClafferty KJ, Nowak ES. Pedestrians in real world collisions. *J Trauma* 1994;36:231–6.
24 Li Y, Fan W. Modelling severity of pedestrian-injury in pedestrian-vehicle crashes with latent class clustering and partial proportional odds model: A case study of North Carolina. *Accident Analysis & Prevention* 2019;131:284–96.
25 Liu J, Khattak AJ, Li X, *et al*. Bicyclist injury severity in traffic crashes: A spatial approach for geo-referenced crash data to uncover non-stationary correlates. *J Safety Res* 2020;73:25–35.
26 Margaritis D, Hoogvelt B, Yd V, *et al*. *An analysis of sport utility vehicles involved in road accidents*. The Netherlands: TNO Automotive, 2005.
27 Martin JL, Lardy A, Laumon B, *et al*. Pedestrian injury patterns according to car and casualty characteristics in france: association for the advancement of automotive medicine (AAAM). 2011.137–46.
28 Newstead S, Watson L, Delaney A, *et al*. Crashworthiness and aggressivity of the Australian light vehicle fleet by major crash type. Report no. 227. Monash University Accident Research Centre; 2004.
29 Pour-Rouholamin M, Zhou H. Investigating the risk factors associated with pedestrian injury severity in Illinois. *J Safety Res* 2016;57:9–17.
30 Robartes E, Chen TD. The effect of crash characteristics on cyclist injuries: An analysis of Virginia automobile-bicycle crash data. *Accident Analysis & Prevention* 2017;104:165–73.
31 Roudsari BS, Mock CN, Kaufman R, *et al*. Pedestrian crashes: higher injury severity and mortality rate for light truck vehicles compared with passenger vehicles. *Inj Prev* 2004;10:154–8.
32 Salon D, McIntyre A. Determinants of pedestrian and bicyclist crash severity by party at fault in San Francisco, CA. *Accident Analysis & Prevention* 2018;110:149–60.
33 Zhao H, Yang G, Zhu F, *et al*. An investigation on the head injuries of adult pedestrians by passenger cars in China. *Traffic Inj Prev* 2013;14:712–7.
34 National Highway Traffic Safety Administration (NHTSA). Data table of pedestrian and cyclist injuries 1994-2015, if struck by an LTV versus passenger car; and data table of pedestrian and cyclist injuries 1994-2015, if struck by an SUV. Both data tables generated from FARS and GES datasets. provided by ncsarequests@dot.gov. 2024 Available: https://crashstats.nhtsa.dot.gov/#!/PublicationList/82
35 National Highway Traffic Safety Administration (NHTSA). Data table of pedestrian and cyclist injuries 2016-2022, if struck by an LTV versus passenger car; and data table of pedestrian and cyclist injuries 2016-2022, if struck by an SUV. Both data tables generated from FARS and CRSS datasets. provided by ncsarequests@dot.gov. 2024 Available: https://crashstats.nhtsa.dot.gov/#!/PublicationList/82
36 Soltani A, Edward Harrison J, Ryder C, *et al*. Police and hospital data linkage for traffic injury surveillance: A systematic review. *Accid Anal Prev* 2024;197:107426.
37 Chong SL, Chiang LW, Allen JC Jr, *et al*. Epidemiology of Pedestrian-Motor Vehicle Fatalities and Injuries, 2006-2015. *Am J Prev Med* 2018;55:98–105.
38 Harmon KJ, Sandt L, Hancock K, *et al*. Using integrated data to examine characteristics related to pedestrian injuries. 2021.
39 Swedler DI, Ali B, Hoffman R, *et al*. Injury and fatality risks for child pedestrians and cyclists on public roads. *Inj Epidemiol* 2024;11:15.
40 Monfort SS, Mueller BC. Pedestrian injuries from cars and SUVs: Updated crash outcomes from the vulnerable road user injury prevention alliance (VIPA). *Traffic Inj Prev* 2020;21:S165–7.
41 Monfort SS, Mueller BC. Bicyclist crashes with cars and SUVs: Injury severity and risk factors. *Traffic Inj Prev* 2023;24:645–51.
42 D'elia A, Newstead S. Pedestrian Injury Outcome as a Function of Vehicle Market Group in Victoria, Australia. *Traffic Inj Prev* 2015;16:709–14.
43 Anderson M. Safety for whom? The effects of light trucks on traffic fatalities. *J Health Econ* 2008;27:973–89.
44 Paulozzi LJ. United States pedestrian fatality rates by vehicle type. *Inj Prev* 2005;11:232–6.
45 White MJ. The 'Arms Rac' on American Roads: The Effect of Sport Utility Vehicles and Pickup Trucks on Traffic Safety. *J Law Econ* 2004;47:333–55.
46 Keall MD, Newstead S. Are SUVs dangerous vehicles? *Accident Analysis & Prevention* 2008;40:954–63.
47 Goodman A, Nix J, Tyndall J, *et al*. SUV Toolkit for Cities: Overview of options for defining and addressing 'oversized vehicles. *Transport for Quality of Life* 2025.