Are front crash prevention systems less effective at preventing rear-end crashes where trucks and motorcycles are struck?

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ABSTRACT

Objective: Automatic emergency braking (AEB) and forward collision warning (FCW) are effective at preventing rear-end crashes, but they may perform better in some rear-end crash scenarios than others. The goal of this study was to estimate the effects of front crash prevention systems equipped to passenger vehicles in crashes where another passenger vehicle, a medium/heavy truck, or a motorcycle is struck and compare effectiveness by struck vehicle type.

Methods: More than 160,000 two-vehicle rear-end crashes were identified where a passenger vehicle with or without FCW and AEB was the striking vehicle and another passenger vehicle, medium/heavy truck, or motorcycle was the struck vehicle. Poisson regression was used to estimate the effect of front crash prevention by struck vehicle type on rear-end crash rates per registered vehicle year, accounting for the state and year of the crash and the make, model year, class, and engine type of the striking vehicle.

Results: Front crash prevention was associated with a 53% reduction in rear-end crash rates when striking another passenger vehicle, which was significantly larger than the reductions of 38% when striking a medium/heavy truck and 41% when striking a motorcycle. Reductions in rear-end injury crash rates when striking a passenger vehicle also were larger than when striking a medium/heavy truck and when striking a motorcycle.

Discussion: If all passenger vehicles were equipped with FCW and AEB that were as effective in crashes striking a truck or motorcycle as they are in crashes with another passenger vehicle, over 5,500 additional crashes with medium/heavy trucks and 500 with motorcycles could potentially be prevented annually in the United States above what would be expected from current front crash prevention systems. Extending front crash prevention testing in consumer information programs to include motorcycle and truck targets could encourage auto manufacturers to improve performance in these crash scenarios.

Keywords: AEB; automatic emergency braking; autonomous emergency braking; forward collision warning; crash avoidance technology

INTRODUCTION

Front crash prevention (FCP) systems like automatic emergency braking (AEB) and forward collision warning (FCW) have been established over the past decade as effective countermeasures to prevent rear-end crashes. FCP equipped to passenger vehicles has been associated with reductions in the risk of a rear-end crash by up to 50% in numerous studies (Aukema et al. 2023; Cicchino 2017; Fildes et al. 2015; Leslie et al. 2021; Spicer et al. 2021a), and these systems are now ubiquitous on new passenger vehicles in the United States. Twenty major U.S. automakers pledged to make AEB standard equipment on 95% of their light-duty cars and trucks by September 2022 (Insurance Institute for Highway Safety 2022). The Highway Loss Data Institute (2023) estimates that 73% of model year 2022 passenger vehicle series had FCP systems as standard equipment, and that in calendar year 2022, 28% of registered passenger vehicles were equipped with the feature.

Although FCP is a proven technology, it does not perform uniformly across all scenarios. Vehicle-to-vehicle AEB with FCW has been shown to be less effective in the dark than in daylight (Aukema et al. 2023), with pedestrian crash prevention systems especially struggling in dark conditions (Cicchino 2022; Kullgren et al. 2023). Greater FCP system effectiveness has been reported at nonintersections compared with intersections, on straightaways compared with curves, and on dry roads compared with wet or snowy roads (Aukema et al. 2023; Spicer et al. 2021a; Spicer et al. 2021b). Cicchino and Zuby (2019) compared the characteristics of rear-end crashes involving striking passenger vehicles with and without AEB and FCW. Vehicles with the systems were more likely than those without them to be in rear-end crashes on roads with a posted speed limit of 70 mph or higher, on snowy or icy roads, and when one of the vehicles were turning, which suggests that FCP is more effectively reducing crashes in more typical rear-end crashes (i.e., at lower speed limits, on dry roads, while traveling straight) and has limitations in these more challenging circumstances that remain.

Current FCP systems also may have limitations in rear-end crash scenarios where a medium/heavy truck or a motorcycle is struck. Passenger vehicles with FCP systems had 61% greater odds than those without FCP of striking a nonpassenger or special use vehicle compared with a passenger car in Cicchino and Zuby's (2019) study. Most of these struck vehicles were medium/heavy trucks, followed by motorcycles. More recently, Kidd et al. (2023a) reported that FCW systems on five model year 2021–2022 passenger vehicles warned less often when they approached a tractor trailer, medium trucks, and motorcycle surrogate targets in track tests than when the target resembled a passenger car.

Motorcycles and medium/heavy trucks present unique safety risks. The small profile of motorcycles can make them more difficult for drivers and vehicle sensors to see than larger vehicles, and motorcyclists do not have protection from their vehicle's structure if they are involved in a crash like other vehicle occupants do. The fatality rate per vehicle mile traveled for motorcyclists in 2021 was nearly 24 times that for passenger car occupants (National Center for Statistics and Analysis 2023). On the other end of the size spectrum, the large mass of medium/heavy trucks increases the severity of crashes with passenger vehicles. Equipping passenger vehicles with crash avoidance systems that prevent crashes with motorcycles and trucks can mitigate these risks because passenger vehicles are often partners in crashes involving these vehicles. Nearly half of motorcycle crashes are two-vehicle crashes where the other vehicle was a passenger vehicle (Teoh 2018), and 12% of all passenger-vehicle-occupant deaths in 2021 occurred in crashes with large trucks (Insurance Institute for Highway Safety 2023a). Teoh (2018) estimated that FCP systems equipped to the passenger vehicle could potentially prevent up to 12% of two-vehicle crashes between a motorcycle and a passenger vehicle. While another passenger vehicle is the struck vehicle in 97% of rear-end crashes where a passenger vehicle is the striking vehicle, a medium/heavy truck (32%) or motorcycle (11%) is the struck vehicle in about 43% of fatal rear-end crashes (Kidd 2022; Kidd et al. 2023b). Thus, the potential of FCP systems to prevent fatalities is especially reliant on its ability to prevent crashes with trucks and motorcycles.

Evidence suggests that FCP may not be as adept at detecting medium/heavy trucks and motorcycles as it is at detecting passenger vehicles, but previous research has not estimated the effects of FCP on crashes where these vehicles are struck. The goal of this study was to evaluate how effective FCP is at preventing rear-end crashes where a passenger vehicle strikes a medium/heavy truck or a motorcycle, and to assess if system effects are larger when a passenger vehicle is the struck vehicle as compared with these nonpassenger vehicles.

METHODS

Analyses compared police-reported crash rates per registered vehicle between passenger vehicles with and without AEB and FCW that struck another passenger vehicle, a medium/heavy truck, or a motorcycle in rear-end crashes.

Data

Data on model year 2016–2020 passenger vehicles with and without AEB and FCW were obtained from a database maintained by the Highway Loss Data Institute of AEB and FCW equipment at the make, model year, series, and model (trim) level. The four-door Honda Civic was considered a series, for instance, and in model year 2019 the EX, EX-L, LX, Sport, and Touring trims were model variants (trim levels) of that series. Vehicles were included in the study if AEB and FCW were either standard or not available on the make/model year/series/model combination; this resulted in a total of 1,843 unique models with FCP and 1,737 without from 26 makes. Models where AEB or FCW were optional were excluded.

Calendar year 2017–2021 police-reported crash data were collected from 18 U.S. states, and relevant variables were coded into a common format. Data were not available in every state for all years. Vehicle Identification Numbers (VINs) in crash data were decoded to extract make, model year, series, and model, which were used to merge crash data with vehicle information data. Registration counts of study vehicles by state and year were computed from data obtained from IHS Markit, a S&P Global company. The analyses were restricted to striking passenger vehicles that were at least 1 year old to ensure a full year of exposure would be included in registered vehicle counts. Rear-end crashes involved two vehicles and were identified by the manner of collision. The striking vehicle was impacted in the front (i.e., 11-, 12-, or 1-o'clock) and the struck vehicle was impacted in the rear (i.e., 5-, 6-, or 7-o'clock) or was coded as sustaining impact to an "other" location that was not the front or side. "Other" points of impact captured codes for underride or motorcycle damage as distinct impact locations that were used by some states.

The type of struck vehicle was classified as a passenger vehicle, medium/heavy truck, or motorcycle. Passenger vehicles were identified from decoding the VIN when it was available. Vehicle type was otherwise derived from the type coded on the police report. Medium/heavy trucks were defined as having gross vehicle weight ratings of over 10,000 lb and excluded pickups and other light trucks, although some states had more ambiguous codes for trucks on their police reports that could capture light trucks or buses along with medium/heavy trucks. Using VINs to identify passenger vehicles allowed large pickup trucks misclassified as "trucks" by police to be correctly recategorized. A total of 11% of struck vehicles classified by police as trucks and 1% classified as motorcycles were recategorized as passenger vehicles through this process. Most of the misclassified trucks were in Texas, which included a generic vehicle type code for "truck" on the police report that was often used for pickup trucks; 50% of the study vehicles coded by Texas police as trucks had VINs that identified them as pickup trucks. In the remaining states, only 3% of vehicles coded as trucks by police were reclassified as passenger vehicles.

Analysis

Poisson regression with a log link was used to compare rear-end crash rates per registered vehicle year (the sum of annual registration counts over multiple years) between striking passenger vehicles with and without FCP. Three models were estimated to examine crashes with different levels of injury severity: all crashes (including those with property damage only or with injuries), injury crashes (involving injuries of any severity, including K, A, B, and C on the KABCO scale), and fatal and serious injury crashes (K or A only).

The dependent variable was rear-end crash counts, and independent variables included state; calendar year; the make, model year, class (two-door car, four-door car, luxury car, sports car, station wagon, minivan, large van, pickup, SUV, luxury SUV), engine type (internal combustion engine, electric, hybrid), and AEB equipment of the striking vehicle; struck vehicle type (passenger vehicle, medium/heavy truck, motorcycle); and the interaction between FCP equipment on the striking vehicle and struck vehicle type. Registration data were linked with crash data by state, calendar year, make, model year, class, engine type, and FCP equipment, and the log of registered vehicle years was used as an offset term to account for exposure differences among vehicles. A Pearson scale parameter was estimated to test and adjust for overdispersion, if present.

The effect of FCP on crashes where a passenger vehicle, medium/heavy truck, or motorcycle was struck was determined from the FCP parameter at each level of struck vehicle type. The interaction between FCP and struck vehicle type was used to test if FCP effectiveness differed between when a passenger vehicle was the struck vehicle and when a medium/heavy truck or motorcycle was stuck.

Percent changes in rear-end crash rates associated with model parameters were expressed by $100(exp(x) - 1)$, where x is the parameter estimate. About 2% of all rear-end crashes, 1% of injury crashes, and 4% of fatal and serious injury crashes involved an unknown struck vehicle type or one other than a passenger vehicle, medium/heavy truck, or motorcycle, and these crashes were not included in the analyses.

RESULTS

Rear-end crash counts and rates per 100,000 registered vehicle years are provided in Table 1. Passenger vehicles were struck in most crashes; medium/heavy trucks were struck in 2% of all crashes, 3% of injury crashes, and 12% of fatal and serious injury crashes; and motorcycles were struck in < 1% of all crashes, 1% of injury crashes, and 5% of fatal and serious injury crashes. Crash rates were lower for vehicles with FCP than for those without it at each combination of struck vehicle type and injury severity.

Table 1

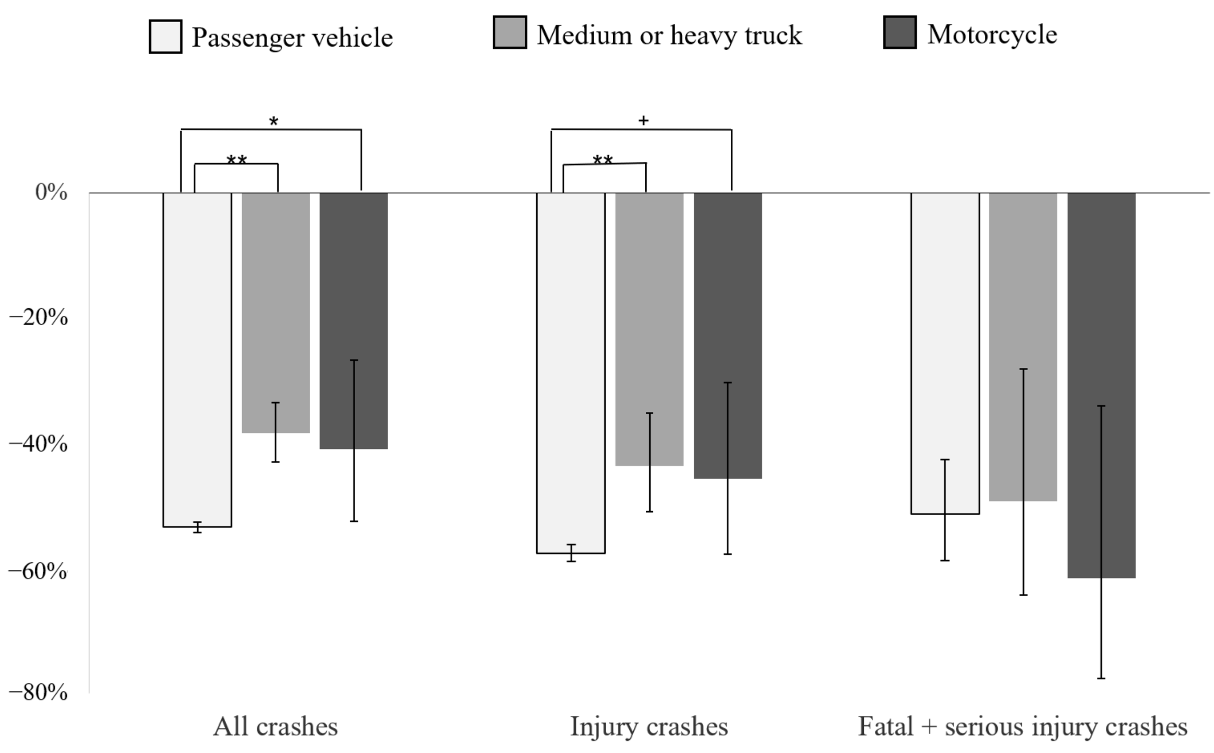
Rear-end crash counts and rates per 100,000 registered vehicle years by front crash prevention (FCP) equipment, struck vehicle type, and crash severity

		Crash severity					
		All		Injury		Fatal and serious injury	
Struck vehicle type	Equipment	Crashes	Crash rate	Crashes	Crash rate	Crashes	Crash rate
Passenger vehicle	With FCP	37,380	141.0	8,534	32.2	257	0.97
	Without FCP	120,038	371.1	30,045	92.9	754	2.33
Medium/ heavy truck	With FCP	1,165	4.4	279	1.1	38	0.14
	Without FCP	2,828	8.7	740	2.3	107	0.33
Motorcycle	With FCP	142	0.5	85	0.3	14	0.05
	Without FCP	360	1.1	234	0.7	52	0.16

Controlling for state, calendar year, and vehicle characteristics, FCP was associated with a 53.4% [95% confidence interval (CI): 52.6%, 54.2%] reduction in rear-end crash rates when striking another passenger vehicle, a 38.4% [95% CI: 33.5%, 43.0%] reduction in rates of rear-ending a medium/heavy truck, and a 41.0% [95% CI: 26.7%, 52.5%] reduction when striking a motorcycle (Figure 1). All reductions were statistically significant ($p < 0.01$). The estimated reduction in striking a passenger vehicle was significantly larger than the reductions in striking a medium/heavy truck ($p < 0.01$) and a motorcycle ($p = 0.03$). Table A1 in the Appendix presents full results of the Poisson regression model assessing the association of FCP with rear-end crash rates.

Results of the two additional Poisson regression models examining FCP in rear-end crashes with injuries or with fatal and serious injuries are also summarized in Figure 1, with full models in Tables A2 and A3 in the Appendix. FCP was associated with statistically significant reductions of 57.6% [95% CI: 56.2%, 58.9%] in rates of striking another passenger vehicle in injury crashes and 51.4% [95% CI: 42.7%, 58.8%] in fatal and serious injury crashes; of 43.7% [95% CI: 35.3%, 51.0%] in striking a medium/heavy truck in injury crashes and of 49.3% [95% CI: 28.2%, 64.3%] in fatal and serious injury crashes; and of 45.7% [95% CI: 30.4%, 57.7%] in striking a motorcycle in injury crashes and 61.6% [95% CI: 34.1%, 77.6%] in fatal and serious injury crashes. Reductions in injury crash rates were larger when a passenger vehicle was struck than compared with a medium/heavy truck ($p < 0.01$) and a motorcycle ($p = 0.05$). Fatal and serious injury crash rate reductions when a passenger vehicle was struck were not significantly different compared with when a medium/heavy truck ($p = 0.82$) or a motorcycle ($p = 0.40$) was struck.

Figure 1. Association of front crash prevention with rear-end crash rates by struck vehicle type from Poisson regression models.



Note. Error bars indicate 95% confidence intervals.

** $p < 0.01$. * $p < 0.05$. + $p < 0.10$.

DISCUSSION

FCP systems have long shown to be effective in preventing rear-end crashes. These crashes overwhelmingly involve striking a passenger vehicle but rear-end crashes where a medium/heavy truck or a motorcycle is struck are more often deadly (Kidd 2022; Kidd et al. 2023b) and have been identified as a condition where FCP may be less effective (Cicchino and Zuby 2019; Kidd et al. 2023a). This study demonstrates that AEB and FCW equipped on passenger vehicles are reducing rear-end crash rates in crashes with motorcycles and medium/heavy trucks. However, the reductions of 38% in rear-end crashes with medium/heavy trucks and 41% in crashes with motorcycles are significantly lower than the 53% reduction estimated in crashes striking other passenger vehicles, which confirms that these crash types present an opportunity to improve FCP performance. Kidd (2022) reported that there were about 39,000 rear-end crashes reported to the police in the United States on average per year during 2016–2019 where passenger vehicles struck medium/heavy trucks and 5,000 where they struck motorcycles. If all passenger vehicles were equipped with AEB and FCW that were as effective in crashes with these vehicles as they are in crashes with another passenger vehicle, over an additional 5,500 crashes with medium/heavy trucks and 500 with motorcycles could be prevented annually above what would be expected from current AEB and FCW systems.

Most FCP testing programs debuted using a Global Vehicle Target that resembles the rear of a car in their testing (European New Car Assessment Programme 2023a). The overwhelming prevalence of rear-end crashes with a struck passenger vehicle combined with evaluations focused on performance with a passenger car encourages auto manufacturers to optimize detection, response, and overall FCP performance in rear-end crashes with passenger cars. Expanding evaluation to include medium/heavy truck and motorcycle targets would incentivize manufacturers to improve how well FCP systems detect these nonpassenger vehicles. The Insurance Institute for Highway Safety is updating their front crash prevention testing program to evaluate if systems can detect a tractor trailer or avoid striking a stationary motorcycle-surrogate target at 50, 60, and 70 km/h. Other NCAP programs internationally, such as the European New Car Assessment Programme (2023b) and the Australasian New Car Assessment Program (CARHS GMBH 2023), have also incorporated motorcycle targets into their FCP evaluations.

Crash reduction estimates were larger for each vehicle type for injury crashes than for all crashes, with non-overlapping confidence intervals between these estimates for passenger vehicles. This is consistent with previous research on AEB effectiveness (Cicchino 2017) and points to the crash severity mitigation benefits that can result from AEB reducing the speed of the striking vehicle in crashes it does not prevent altogether. Aukema et al. (2023) previously reported that AEB and FCW are associated with a 42% reduction in front-to-rear crashes resulting in serious or fatal injuries. The current research adds to this small body of evidence that demonstrates that FCP systems can prevent these severe crashes. Sample sizes were small in the analysis of fatal and serious injury crashes, especially for crashes where a motorcycle was struck, and insufficient for determining if reductions differed by struck vehicle type. Improving FCP performance in crash scenarios where the risk of a fatality is greatest, including when medium/heavy trucks and motorcycles are struck and at higher speeds (Kidd 2022; Kidd et al. 2023b), should lead to even better performance in preventing the most dangerous rear-end crashes.

Although the analyses controlled for some factors that affect crash risk, such as vehicle class and model year, it did not account for all factors that differ between drivers who choose vehicles with and without FCP. Using registration years as the exposure measure similarly does not consider how the type of driving exposure might make a driver more likely to encounter trucks or motorcycles. Heavy trucks travel a larger percentage of their miles on interstate highways than passenger vehicles (Federal Highway Administration 2023), and motorcycles travel comparatively more often during warmer weather. These analyses do not disentangle the contributions of FCP's difficulty in detecting medium/heavy trucks, as demonstrated in test track research (Kidd et al. 2023a), from degraded performance at higher speeds (Cicchino and Zuby 2019) to the overall lower FCP effectiveness in crashes with trucks.

FCP that avoids rear-end crashes with motorcycles and medium/heavy trucks can be added to the toolbox of countermeasures to prevent or mitigate the severity of these crashes. Countermeasures such as motorcycle helmets (Norvell and Cummings 2002) and stronger underride guards (Brumbelow and Blanar 2010) reduce the severity of motorcycle and heavy truck crashes when they occur. Equipping heavy trucks (Teoh 2021) with FCP systems lowers the risk of rear-end crashes where they are the striking vehicles, and equipping motorcycles with FCP has the promise to do so as well (Lucci et al. 2021). Developing crash avoidance systems for passenger vehicles that can detect medium/heavy trucks and motorcycles in other common crash scenarios also have the potential to drive crashes down further. For example, Teoh (2023) reported that over a quarter of two-vehicle motorcycle crashes involved the other vehicle turning left in front of the motorcycle, which could be addressed by left-turn assist systems that detect motorcycles. More than 6,000 motorcyclists died in traffic crashes in 2021, and over 4,000 more people were killed in crashes involving heavy trucks (Insurance Institute for Highway Safety 2023b). As fatalities involving trucks and motorcycles continue to increase in the United States, we need to use all tools at our disposal related to changing vehicle design, driver behavior, and roadway design to drive these fatalities downwards.

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APPENDIX

Table A1

Poisson regression model results of rear-end-striking crash rates per registered vehicle year

Parameter	Estimate	Standard error	*p* value
Intercept	–7.4352	0.1865	<0.01
Calendar year – vs. 2017			
2018	0.6893	0.0149	<0.01
2019	0.8912	0.0145	<0.01
2020	0.6430	0.0146	<0.01
2021	1.0628	0.0144	<0.01
Model year – vs. 2016			
2017	–0.2018	0.0088	<0.01
2018	–0.4040	0.0098	<0.01
2019	–0.6029	0.0114	<0.01
2020	–0.6862	0.0154	<0.01
Vehicle class – vs. pickup			
Sports car	0.0671	0.0333	0.04
Two-door car	0.6768	0.0290	<0.01
Four-door car	0.7730	0.0117	<0.01
Station wagon	0.4150	0.0189	<0.01
Luxury car	0.9021	0.0556	<0.01
Minivan	0.0142	0.0307	0.64
Large van	0.4986	0.0179	<0.01
SUV	0.1474	0.0106	<0.01
Luxury SUV	0.6342	0.0453	<0.01
Engine type – vs. ICE			
Hybrid	–0.2343	0.0248	<0.01
Electric	–0.9174	0.0824	<0.01
Struck vehicle type – vs. passenger vehicle			
Medium/heavy truck	–3.7482	0.0212	<0.01
Motorcycle	–5.8095	0.0590	<0.01
FCP vs. none	–0.7643	0.0087	<0.01
Interaction between FCP and struck vehicle type			
FCP vs. none and medium/heavy truck vs. passenger vehicle	0.2798	0.0394	<0.01
FCP vs. none and motorcycle vs. passenger vehicle	0.2364	0.1109	0.03

Note. SUV = sport utility vehicle. ICE=internal combustion engine. FCP = front crash prevention.

For brevity, state and vehicle make effects not shown.

Table A2

Poisson regression model results of rear-end-striking crash rates in injury crashes per registered vehicle year

Parameter	Estimate	Standard error	*p* value
Intercept	–9.7026	0.5040	<0.01
Calendar year – vs. 2017			
2018	0.6465	0.0267	<0.01
2019	0.8430	0.0258	<0.01
2020	0.6069	0.0259	<0.01
2021	1.0125	0.0256	<0.01
Model year – vs. 2016			
2017	–0.1910	0.0158	<0.01
2018	–0.3903	0.0175	<0.01
2019	–0.5534	0.0205	<0.01
2020	–0.6691	0.0279	<0.01
Vehicle class – vs. pickup			
Sports car	0.0743	0.0576	0.20
Two-door car	0.6362	0.0523	<0.01
Four-door car	0.7645	0.0208	<0.01
Station wagon	0.3901	0.0339	<0.01
Luxury car	0.8743	0.1038	<0.01
Minivan	0.0133	0.0557	0.81
Large van	0.5076	0.0315	<0.01
SUV	0.1250	0.0189	<0.01
Luxury SUV	0.6829	0.0843	<0.01
Engine type – vs. ICE			
Hybrid	–0.3413	0.0483	<0.01
Electric	–0.9803	0.1535	<0.01
Struck vehicle type – vs. passenger vehicle			
Medium/heavy truck	–3.7038	0.0372	<0.01
Motorcycle	–4.8551	0.0657	<0.01
FCP vs. none	–0.8570	0.0160	<0.01
Interaction between FCP and struck vehicle type			
FCP vs. none and medium/heavy truck vs. passenger vehicle	0.2832	0.0714	<0.01
FCP vs. none and motorcycle vs. passenger vehicle	0.2460	0.1273	0.05

Note. SUV = sport utility vehicle. ICE=internal combustion engine. FCP = front crash prevention.

For brevity, state and vehicle make effects not shown.

Table A3

Poisson regression model results of rear-end-striking crash rates in fatal and serious crashes per registered vehicle year

Parameter	Estimate	Standard error	*p* value
Intercept	–11.8005	0.2660	<0.01
Calendar year – vs. 2017			
2018	0.2800	0.1396	0.04
2019	0.7089	0.1313	<0.01
2020	0.4732	0.1307	<0.01
2021	1.0296	0.1270	<0.01
Model year – vs. 2016			
2017	–0.1823	0.0835	0.03
2018	–0.3514	0.0916	<0.01
2019	–0.4808	0.1037	<0.01
2020	–0.5755	0.1334	<0.01
Vehicle class – vs. pickup			
Sports car	0.3071	0.2751	0.26
Two-door car	0.6818	0.2633	<0.01
Four-door car	0.7962	0.1044	<0.01
Station wagon	0.2517	0.1824	0.17
Luxury car	1.0846	0.4994	0.03
Minivan	–0.0857	0.3005	0.78
Large van	0.2838	0.1622	0.08
SUV	–0.0056	0.0947	0.95
Luxury SUV	0.7345	0.3959	0.06
Engine type – vs. ICE			
Hybrid or electric [a]	0.0009	0.1953	>0.99
Struck vehicle type – vs. passenger vehicle			
Medium/heavy truck	–1.9526	0.0929	<0.01
Motorcycle	–2.6741	0.1289	<0.01
FCP vs. none	–0.7211	0.0842	<0.01
Interaction between FCP and struck vehicle type			
FCP vs. none and medium/heavy truck vs. passenger vehicle	0.0411	0.1817	0.82
FCP vs. none and motorcycle vs. passenger vehicle	–0.2359	0.2783	0.40

Note. SUV = sport utility vehicle. ICE=internal combustion engine. FCP = front crash prevention.

For brevity, state and vehicle make effects not shown.

[a] Hybrid and electric vehicles were combined due to sparse crash counts.