Effects of forward collision warning and automatic emergency braking on rear-end crashes involving pickup trucks

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Contents

ABSTRACT

Objective: About 1 in 5 registered U.S. passenger vehicles is a pickup truck, but safety technology tends to be available on pickups later than other passenger vehicle types. The objective of this study was to estimate the effects of forward collision warning (FCW) and automatic emergency braking (AEB) on pickups.

Methods: Rear-end crashes where a pickup with optional FCW or AEB was the striking vehicle were identified in 25 U.S. states during 2017–2020. Quasi-induced exposure was performed with logistic regression to compare rear-end-striking crashes between vehicles with and without the systems relative to being struck in the rear. Rear-end-striking crash rates per registered vehicle year were also compared between equipped and non-equipped pickups with Poisson regression. The association of the systems with severity in the rear-end-striking crashes that occurred was examined with logistic regression.

Results: In the quasi-induced exposure analysis, AEB was associated with statistically significant 34% reductions in the risk of a rear-end-striking crash of any severity and with any injuries, and a 76% reduction in the risk of a rear-end-striking crash with serious or fatal injuries ($p = 0.09$). FCW was associated with statistically significant declines of 22% in the risk of a rear-end-striking crash with any injuries and 71% in the risk of a rear-end-striking crash with serious or fatal injuries, but FCW was not associated with a change in all rear-end-striking crashes. Results were similar in Poisson regression models for all but FCW's effect on all rear-end-striking crashes. Rear-end-striking crashes involving pickups with FCW were significantly less likely to result in any injuries or serious/fatal injuries than those involving pickups without the system. AEB was associated with a nonsignificant reduction in the odds of serious/fatal injuries when a rear-end strike occurred and no change in the odds of any injuries.

Discussion: Consistent benefits for front crash prevention systems have been established for a wide range of vehicle types, including cars, SUVs, large trucks, and now pickups. Gaps in proposed U.S. regulations should be filled so that AEB is required equipment on all new vehicles.

Keywords: light truck vehicles; autonomous emergency braking; AEB; FCW; front crash prevention; crash avoidance technology

INTRODUCTION

One in five registered U.S. passenger vehicles in 2021 was a pickup truck (Insurance Institute for Highway Safety [IIHS] analysis of data obtained from IHS Markit). Pickups have been increasing in size, with the average curb weight of pickups registered in the United States rising from about 4,400 lbs in 2011 to over 4,800 lbs in 2021. This increase in size has perpetuated incompatibilities between pickups and passenger cars. Pickups remain over 150% more likely to kill the driver of a struck car in a two-vehicle crash compared with when a car crashes with another car, while SUV-car incompatibility has shrunk in recent years (Monfort and Nolan 2019).

Despite the heightened risk of serious injury or death to partner vehicle occupants in multivehicle crashes involving pickup trucks, pickups have been the last passenger vehicles to be equipped with advanced driver assistance systems to prevent these crashes. Forward collision warning (FCW) warns drivers when they are at risk of rear-ending another vehicle, and automatic emergency braking (AEB) applies the brakes if drivers do not respond in time to an impending rear-end collision. The first car was equipped with FCW in the United States in model year (MY) 2000, and the first SUV in 2006; cars became available with AEB in 2006 and SUVs followed in 2009. In contrast, FCW first was optional equipment on a pickup on the MY 2014 Chevrolet Silverado 1500 and GMC Sierra 1500, and AEB on the MY 2017 versions of these same models along with the MY 2017 Honda Ridgeline. This has translated to lower AEB equipment rates for pickups that are on the road today compared with cars and SUVs. AEB was standard equipment on 74% of new MY 2021 car series and 87% of new MY 2021 SUV series, but only 24% of MY 2021 pickup series. Among registered vehicles of all model years in calendar year 2021, AEB was a standard or optional feature on 25% of cars, 40% of SUVs, and 14% of pickups.

Front crash prevention systems are effective at averting rear-end crashes for a range of vehicle types. FCW has been shown to reduce the risk of rear-end crashes involving passenger vehicles by up to 27% (Cicchino 2017, 2018; Leslie et al. 2021; Leslie et al. 2022) and large trucks by 44% (Teoh 2021), and AEB is associated with risk reductions of up to 50% in rear-end crashes involving passenger vehicles

(Cicchino 2017, 2018; Fildes et al. 2015; Leslie et al. 2021; Leslie et al. 2022; Spicer et al. 2021) and 41% involving large trucks (Teoh 2021). Larger benefits have been documented for AEB on passenger vehicles for rear-end crashes with injuries, while the injury mitigation effects of FCW have been inconsistent (Cicchino 2017, 2018; Leslie et al. 2021; Leslie et al. 2022).

Comparatively less research has examined front crash prevention system effects for pickups specifically. Pickup trucks have been included in evaluations of FCW and AEB on General Motors (Leslie et al. 2021) and Toyota (Spicer et al. 2021) vehicles that combined pickups, SUVs, and cars in analyses, but the effect of these systems for pickups alone was not estimated in these studies. One study reported that AEB on General Motors pickups was associated with a significant reduction in rear-end crash risk, while FCW was not (Leslie et al. 2022). The current study builds on prior research by estimating the effects of FCW and AEB on pickups for rear-end crashes of increasing severities, including those with any injuries and those with serious or fatal injuries.

METHODS

Data

Model year 2017–2020 pickup trucks were eligible for the study if they offered FCW or AEB as an optional feature and the presence or absence of the system could be derived from the Vehicle Identification Number (VIN). In other words, there were VIN-identifiable trim levels with the feature as standard or as not available. Equipment with FCW or AEB was determined from a database maintained by the Highway Loss Data Institute of advanced driver assistance features linked as standard, optional, or not available to VIN-discernible trims.

The final population of study vehicles with optional AEB comprised the 2018 Chevrolet Silverado 1500 crew cab, 2017–2018 GMC Sierra 1500 crew cab, 2020 GMC Sierra 2500 HD and 3500 HD crew cab, and 2017–2019 Honda Ridgeline crew cab. Pickups with optional FCW were the 2017–2019 Chevrolet Silverado 2500 HD and 3500 HD crew cab, 2017–2019 GMC Sierra 2500 HD and 3500 HD crew cab, and 2017–2020 GMC Canyon crew cab.

Only trims where the feature was standard or not available were included; if a feature was optional on a trim, that trim was excluded from analyses. For example, on the 2018 Chevrolet Silverado 2500 HD, FCW was standard on the High Country trim, optional on the LT and LTZ trims, and not available on the WT trim, and so only the High Country and WT trims were included in the study. FCW or AEB came packaged with lane departure warning or prevention on all study models, and on some vehicles AEB was packaged with blind spot monitoring and/or adaptive cruise control. Lane departure warning and blind spot monitoring are not expected to act on rear-end crashes. Adaptive cruise control could potentially enhance AEB effects, but because it is meant to be used on highways and must be activated when drivers choose to use it, it would be expected that adaptive cruise control would be turned off during many rear-end scenarios.

Annual vehicle registration counts disaggregated by calendar year, state, and vehicle make/model year/series/trim were computed with data obtained from IHS Markit. Police-reported crash data during 2017–2020 were extracted from 25 states (Table A1, Appendix). Variables in each state's dataset were coded into a common format. Rear-end crashes were defined as multivehicle crashes where the crash type was a rear end and no involved vehicles were backing. Striking vehicles were identified as having an initial point of impact to the to the front (11-, 12-, or 1 o'clock), and struck vehicles to the rear (5-, 6-, or 7 o'clock).

Analyses

Crash rates per registered vehicle year

Two analysis approaches were used to examine the relationship between FCW/AEB and crash risk. Rear-end-striking crash involvements per registered vehicle year (the sum of annual registration counts over multiple years) were compared between pickups with and without FCW or AEB on models where each system was optional with Poisson regression. This analysis was restricted to vehicles at least 1 year old to ensure a full year of exposure would be included in registered vehicle counts. Because the newest crash data available were from 2020, the MY 2020 GMC Canyon, Sierra 2500 HD, and Sierra 3500 HD were not included in this analysis, and calendar year 2017 crash data were also excluded because the oldest study vehicles were MY 2017. Six separate models were constructed to examine each combination of system (FCW and AEB) at three levels of crash injury severity (all crashes, crashes involving any injuries [K, A, B, or C on KABCO scale]), and crashes involving serious or fatal injuries [K or A on KABCO scale]). The log of registered vehicle years was an offset term, and models controlled for calendar year, state, make/model combination, and model year. Pearson scale parameters were estimated within the Poisson models to test and adjust for potential overdispersion.

Quasi-induced exposure

A second analysis approach used the quasi-induced exposure method. Rather than using registrations as the exposure measure, quasi-induced exposure compares involvement in the crash type expected to be affected by the system (rear-end striking) to a crash type expected to be unaffected by the technology of interest (Keall and Newstead 2009). This method uses involvement in the unaffected crash type as a proxy for distance driven, which is not captured in registration data. Like other evaluations of AEB effects using quasi-induced exposure (Cicchino 2022; Fildes et al. 2015; Leslie et al. 2021), rear-end-struck crash involvements were the nonsensitive crash type.

Cicchino (2017) reported that AEB was associated with increases in rear-end-struck crash rates, which could potentially result from vehicles with AEB getting struck in the rear after sudden AEB braking. If this were the case with the current study vehicles, it would bias effect estimates towards indicating a benefit for the system. Poisson regression was performed on the relationship of FCW and AEB to rear-end-struck crash rates per registered vehicle year using methods described earlier to investigate this possibility.

Logistic regression was used to examine the odds that a pickup was involved in a rear-end-striking crash. Models included the same covariates as the Poisson regression analyses, plus driver age and gender, which were unavailable in vehicle registrations but could be determined for both crashes and exposure through quasi-induced exposure. Six models were similarly constructed for each combination of system and injury severity. All rear-end-struck crash involvements were used as the comparison crash type in each analysis. These models were not restricted by vehicle age, so the 2020 model year vehicles and calendar year 2017 crash data were included.

Injury mitigation/prevention

When a crash is not prevented by FCW or AEB, the system may still lower the severity of the crash if the speed of the striking vehicle is slowed by the driver braking in response to a warning or by the system's emergency braking. To test this hypothesis, logistic regression models examined the association of FCW and AEB with the odds of any injuries and of serious or fatal injuries when a study vehicle was the striking vehicle in a rear-end crash. Models controlled for the same covariates as in the quasi-induced exposure analysis and were also unrestricted by vehicle age. This analysis did not include rear-end-struck crash involvements, as it investigated the odds that a crash that occurred involved an injury rather than the risk of being involved in a crash per unit of exposure.

Sparse levels of covariates were combined in some analyses. The GMC Sierra 2500 HD with optional AEB was not involved in any rear-end-striking crashes with serious or fatal injuries and was excluded from analyses examining that injury severity level. Model parameters were exponentiated and interpreted as rate ratios (RRs) from Poisson regression models and odds ratios (ORs) from logistic regression models, and percent changes in these rates and odds associated with FCW or AEB were expressed by $100(exp\,(x) - 1)$, where x is the parameter estimate for FCW or AEB.

RESULTS

Rear-end crash counts and rates per 10,000 registered vehicle years for pickups at least 1 year old with and without AEB and FCW are summarized in Table 1. A study vehicle at least 1 year old was the striking vehicle in 2,042 total rear-end crashes (914 optional-AEB vehicles, 1,128 optional-FCW vehicles), 546 rear-end crashes with any injuries (234 optional-AEB vehicles, 312 optional-FCW vehicles), and 24 rear-end crashes with serious or fatal injuries (10 optional-AEB vehicles, 14 optional-FCW vehicles). Rear-end-striking crash involvement rates were lower for vehicles with front crash prevention systems than for those without at all severity levels. All crashes involving optional-FCW vehicles were General Motors models, and among optional-AEB vehicles, 78% were involved in any rear-end crashes (712 vehicles), 76% in rear-end crashes with injuries (178 vehicles), and 90% in rear-end crashes with serious or fatal injuries (9 vehicles) were from General Motors.

Crash rates per registered vehicle year

Table 2 presents results of the Poisson regression models examining the relationship of AEB and FCW to rear-end-striking crash rates (expanded model results appear in Tables A2 and A3 in the Appendix). AEB was associated with statistically significant reductions of 43% and 42%, respectively, in rear-end-striking crash rates for all crashes and those with injuries, and a nonsignificant 77% reduction in serious and fatal injury crash rates. FCW was associated with a statistically significant 17% reduction in crash rates for all rear-end-striking crashes, a significant 29% reduction in rear-end-striking injury crash rates, and a 54% reduction in serious and fatal injury crash rates that was not statistically significant. Pearson scale parameters ranged from 0.88 to 1.60 in these models, indicating minimal overdispersion when present.

FCW and AEB were also associated with reductions in rear-end-struck crash involvement rates in Poisson regression models, although the reductions were smaller than those for striking involvements. Rear-end-struck crash rates were 9% lower among vehicles with FCW than without (RR, 0.91; 95% confidence interval [CI], 0.81–1.03, $p = 0.13$) and 13% lower among vehicles with AEB than without

(RR, 0.87; 95% CI, 0.79–0.96, $p = 0.006$). Only the effect for AEB was statistically significant. This indicates that the study vehicles did not experience an increase in being struck in the rear due to sudden braking after FCW or AEB activations, and that quasi-induced exposure analyses would not be biased towards exhibiting benefits for these systems by using rear-end-struck involvements as the control crash type.

Quasi-induced exposure

Table 3 summarizes results of the quasi-induced exposure analysis. Because this analysis was not restricted by vehicle age, it included more crashes than the analysis of crashes per registered vehicle year: 2,929 total rear-end-striking crashes (1,259 optional-AEB vehicles, 1,670 optional-FCW vehicles), 763 rear-end-striking crashes with any injuries (315 optional-AEB vehicles, 448 optional-FCW), and 34 rear-end striking-crashes with serious or fatal injuries (11 optional-AEB vehicles, 23 optional-FCW vehicles). Pickups with optional AEB were the struck vehicle in 2,567 rear-end crashes and those with optional FCW were the struck vehicle in 1,989. The odds of a rear-end-striking crash of any severity or with any injuries were 34% lower among vehicles with AEB than those without, and these differences were statistically significant (expanded model results in Table A4 in the Appendix). AEB was associated with a 76% reduction of the odds of a rear-end-striking crash with serious or fatal injuries ($p = 0.09$). The odds of being in a rear-end crash of any severity were not lower among vehicles with FCW than those without, but odds in a crash with any injuries or serious/fatal injuries were significantly lower, by 22% and 71%, respectively (expanded model results in Table A5 in the Appendix).

Injury mitigation/prevention

The effects of front crash prevention systems on injury mitigation/prevention appear in Table 4. When a study vehicle was the striking vehicle in a rear-end crash, FCW was associated with a 26% reduction in the odds of the crash resulting in any injuries and a 75% reduction in the odds of serious or fatal injuries (both statistically significant; expanded model results in Table A6 in the Appendix). AEB was associated with a 64% reduction in the odds of serious or fatal injuries that was not statistically significant, and no change in the odds of any injuries (expanded model results in Table A7 in the Appendix).

DISCUSSION

Just as it is for cars, SUVs, and large trucks (Cicchino 2017; Fildes et al. 2015; Teoh 2021), AEB is reducing rear-end crashes for pickup trucks. FCW was not associated with consistent benefits for all rear-end crashes but did reduce the risk of rear-end crashes with any injuries or serious/fatal injuries. This is the first study documenting a reduction in the most severe rear-end crashes attributable to front crash prevention systems, and this result is especially promising to find in a sample of pickup trucks given the outsize risk they pose to smaller crash partners in multivehicle crashes (Hubele and Kennedy 2018; Monfort and Nolan 2019; Ossiander et al. 2014). Risk of a rear-end crash resulting in any injuries or serious/fatal injuries was also much lower among pickups with AEB than those without, but the precision for serious/fatal injuries was lower than in the analysis of FCW and will need to be revisited when a larger sample of severe rear-end crashes is available.

One mechanism by which FCW reduced rear-end crashes with any injuries or serious/fatal injuries on pickups in this study was by lessening the severity of crashes that occurred, likely by lowering the speed of the striking vehicle when a crash was not prevented entirely. This is consistent with Teoh (2021), who found that the average speed of a large truck with FCW involved as a striking vehicle in a rear-end crash was reduced by 70% on average between the onset of the warning and the crash. Injury mitigation has long been expected to be a feature of front crash prevention systems (Krafft et al. 2009; Kusano and Gabler 2012), and this finding builds support that it is occurring in the real world.

Additional AEB capabilities, such as performance at higher speeds or pedestrian detection, may be beneficial for pickups. Cicchino and Zuby (2019) reported that rear-end crashes involving striking vehicles with AEB are overrepresented at higher speed limits, suggesting that some AEB systems are less effective at higher speeds; pickups are driven more often than other passenger vehicle types in rural areas, where speeds are higher on average (Clark 2003; Rakauskas et al. 2009; Weiss et al. 2001). In 2020, a larger proportion of U.S. rear-end crashes with a pickup as the striking vehicle occurred at 55 mph or higher (28%) compared with those where the striking vehicle was a car (23%) or SUV (20%). AEB that can detect pedestrians has been shown to reduce pedestrian crashes (Cicchino 2022), and pickups and other light truck vehicles pose a greater risk of seriously injuring or killing a pedestrian in a crash than cars (Desapriya et al. 2010; Lefler and Gabler 2004; Paulozzi 2005). Yet, current pedestrian AEB systems struggle at higher speeds and in the dark without street lighting (Cicchino 2022), which are conditions more prevalent in rural areas, and so improvements to these functionalities could be especially important to preventing or mitigating the severity of pedestrian crashes involving pickups.

One limitation of this study is that most of the pickups with optional FCW were much larger than the pickups with optional AEB, and it is impossible to know how much of the differences in effects between system types are due to the function of the systems themselves or to the different vehicle populations. Of the pickups with optional FCW, the Chevrolet Silverado 2500 HD/GMC Sierra 2500 HD had gross vehicle weight ratings (GVWR) close to 10,000 lbs, and the GVWRs of the Chevrolet Silverado 3500 HD/GMC Sierra 3500 HD exceeded 10,000 lbs. The MY 2020 GMC Sierra 2500 HD and 3500 HD were the only pickups with optional AEB that were as heavy, and they made up a much smaller proportion of vehicles in that analysis. Most pickups were from a single automaker (General Motors) and it is also unknown how closely results would generalize to other pickups, although other evaluations of the General Motors front crash prevention systems have produced comparable effect sizes to systems from other automakers (Cicchino 2018; Leslie et al. 2021; Leslie et al. 2022).

Two analysis methods were used to account for their differing weaknesses. The registration data from IHS Markit is for privately owned passenger vehicles, and the crash data may have included pickups that are commercially owned and operated. This would affect results if trims without FCW or AEB are used commercially more often than those with the system, or vice versa, and may possibly be an explanation for why FCW was associated with a reduction in all rear-end crashes when looking at crashes per registered vehicle but not in the quasi-induced exposure analysis. Differences in mileage and type of exposure between drivers of different trims, which would not be captured in registered vehicle data but may be better accounted for in quasi-induced exposure analysis, is another potential explanation. More broadly, because study data relied on systems that were tied to trims, differences between drivers of the more expensive trims with the systems and less costly trims without them could have influenced crash rates. This may explain why vehicles with the systems also had lower rates of being struck in the rear per registered vehicle year; it also substantiates the importance of corroborating results from the analysis comparing crash rates per registered vehicle year with quasi-induced exposure. Vehicles with the systems could have also been possibly struck in the rear less often if driver experience with warnings resulted in smoother braking profiles to avoid future warnings; if this were the case, effect sizes were underestimated in the quasi-induced exposure analysis. Quasi-induced exposure is not a perfect surrogate for actual exposure (Keall and Newstead 2009), but it is reassuring that results from both methods converged for AEB in all analyses and for FCW for injury and serious injury/fatality crashes.

Front crash prevention systems are effective at reducing rear-end injury crashes involving pickup trucks, and automakers should accelerate equipping pickups with these systems. A voluntary commitment by automakers and legal requirements will ensure that AEB will be standard equipment on most vehicles in the United States, but there are gaps for the largest pickups and other medium trucks. Major U.S. automakers have committed to making AEB standard equipment on virtually all light vehicles with GVWRs of 8,500 lbs or less by September 1, 2022 and with GVWRs between 8,501 and 10,000 lbs by September 1, 2025 (Insurance Institute for Highway Safety 2016). While many pickups were covered under this commitment in 2022, some will not be until 2025 and the largest pickups do not fall under it at all. The Infrastructure Investment and Jobs Act passed in 2021 orders the U.S. Department of Transportation to issue rulemaking within two years of its passage requiring AEB on new large trucks with GVWRs of greater than 26,000 lbs; however, this requirement is not extended to Class 3–6 trucks. Because consistent benefits for front crash prevention systems have been established for a wide range of vehicle types, including cars, SUVs, large trucks, and now pickups, AEB should be required on all new vehicles of all types so that the largest pickups and other medium trucks will be equipped.

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TABLES

Table 1

Rear-end-striking crash rates per 10,000 registered vehicle years among pickups at least 1 year old

		Optional AEB		Optional FCW	
Severity	Equipped	Crashes	Rate	Crashes	Rate
All crashes	Yes	383	25.4	590	47.3
	No	531	42.6	538	54.1
Injury crashes	Yes	101	6.7	154	12.4
	No	133	10.7	158	15.9
Serious or fatal injury crashes	Yes	2	0.1	5	0.4
	No	8	0.6	9	0.9

Table 2

Poisson regression model results of rear-end-striking crash rates per registered vehicle year associated with AEB and FCW, by crash severity

	AEB		FCW	
Severity	RR (95% CI)	*p*	RR (95% CI)	*p*
All crashes	0.57 (0.49, 0.66)	<.001	0.83 (0.72, 0.97)	0.02
Any injuries	0.58 (0.45, 0.75)	<.001	0.71 (0.56, 0.90)	0.004
Serious or fatal injuries	0.23 (0.03, 1.82)	0.16	0.46 (0.14, 1.49)	0.20

Table 3

Logistic regression model results of quasi-induced exposure analysis examining the odds of a rear-end-striking crash associated with AEB and FCW, by severity

	AEB		FCW	
Severity	OR (95% CI)	*p*	OR (95% CI)	*p*
All crashes	0.66 (0.57, 0.78)	<.001	0.96 (0.83, 1.12)	0.62
Any injuries	0.66 (0.50, 0.86)	<.001	0.78 (0.61, 0.99)	0.04
Serious or fatal injuries	0.24 (0.05, 1.22)	0.09	0.29 (0.10, 0.82)	0.02

Table 4

Logistic regression analysis of the odds that rear-end-striking crash resulted in any injuries or serious/fatal injuries associated with AEB and FCW

	AEB		FCW	
Severity	OR (95% CI)	*p*	OR (95% CI)	*p*
Any injuries	0.98 (0.73, 1.31)	0.89	0.74 (0.58, 0.96)	0.02
Serious or fatal injuries	0.36 (0.07, 1.84)	0.22	0.25 (0.09, 0.74)	0.01

APPENDIX

Abbreviations

AEB: automatic emergency braking

FCW: forward collision warning

MY: model year

Table A1

Police-reported crash data availability by state and year

State	Years available
CT	2017–2020
FL	2017–2020
GA	2017–2020
IA	2017–2019
ID	2017–2020
IL	2017–2020
KS	2017–2020
LA	2017–2020
MD	2017–2020
MI	2017–2020
MN	2017–2020
MO	2017–2020
NC	2017–2019
ND	2017–2019
NE	2017–2019
NJ	2017–2020
NM	2019–2020
OH	2017–2020
PA	2017–2020
SD	2017–2020
TN	2017–2019
TX	2017–2020
UT	2018
WI	2017–2019
WY	2017–2020

Table A2

Poisson regression model results of rear-end-striking crash rates per registered vehicle year associated with AEB, by crash severity

Parameter	Rate ratio (95% confidence interval) All crashes (n = 914)	Any injuries (n = 234)	Serious or fatal injuries (n = 10)
AEB	0.57 (0.49, 0.66)	0.58 (0.45, 0.75)	0.23 (0.03, 1.82)
Calendar year – vs. 2018			
2019	1.06 (0.87, 1.30)	1.00 (0.70, 1.43)	1.07 (0.11, 10.91)
2020	0.75 (0.60, 0.93)	0.66 (0.44, 0.98)	0.37 (0.02, 5.79)
Model year – vs. 2017			
2018	1.00 (0.83, 1.20)	1.01 (0.72, 1.42)	0.55 (0.03, 10.00)
2019	1.18 (0.82, 1.69)	1.36 (0.71, 2.59)	*
Vehicle – vs. Honda Ridgeline			
Chevrolet Silverado 1500	1.96 (1.52, 2.52)	1.64 (1.02, 2.64)	7.64 (0.19, 304.87)
GMC Sierra 1500	1.91 (1.58, 2.31)	1.99 (1.42, 2.80)	4.08 (0.25, 66.36)

Note: For brevity, state effects not shown.
* MY 2019 combined with MY 2018 due to sparse data.

Table A3

Poisson regression model results of rear-end-striking crash rates per registered vehicle year associated with FCW, by crash severity

Parameter	Rate ratio (95% confidence interval) All crashes (n = 1,128)	Any injuries (n = 312)	Serious or fatal injuries (n = 14)
FCW	0.83 (0.72, 0.97)	0.71 (0.56, 0.90)	0.46 (0.14, 1.49)
Calendar year – vs. 2018			
2019	0.84 (0.67, 1.06)	0.85 (0.59, 1.23)	0.13 (0.02, 0.90)
2020	0.70 (0.55, 0.89)	0.66 (0.45, 0.98)	0.24 (0.04, 1.35)
Model year – vs. 2017			
2018	1.19 (1.00, 1.42)	1.31 (0.99, 1.73)	1.07 (0.18, 6.31)
2019	0.97 (0.77, 1.22)	1.24 (0.86, 1.78)	1.11 (0.16, 7.61)
Vehicle – vs. GMC Sierra 2500 HD			
Chevrolet Silverado 2500 HD	1.05 (0.88, 1.25)	0.81 (0.61, 1.07)	1.20 (0.32, 4.55)
Chevrolet Silverado 3500 HD	1.23 (0.98, 1.55)	1.21 (0.85, 1.71)	1.27 (0.23, 7.04)
GMC Canyon	1.02 (0.78, 1.33)	1.01 (0.68, 1.51)	0.97 (0.10, 9.10)
GMC Sierra 3500 HD	1.12 (0.89, 1.42)	1.15 (0.80, 1.66)	0.81 (0.09, 7.19)

Note: For brevity, state effects not shown.

Table A4

Logistic regression model results of quasi-induced exposure analysis examining the odds of a rear-end-striking crash associated with AEB, by severity

	Odds ratio (95% confidence interval)		
Parameter	All crashes (*n* = 1,259)	Any injuries (*n* = 315)	Serious or fatal injuries (*n* = 11)
AEB	0.66 (0.57, 0.78)	0.66 (0.50, 0.86)	0.24 (0.05, 1.22)
Driver gender – vs. female			
Male	1.19 (0.96, 1.46)	1.02 (0.72, 1.45)	+
Unknown	1.06 (0.46, 2.41)	0.68 (0.14, 3.33)	+
Driver age – vs. 25–64			
< 25	1.93 (1.49, 2.50)	2.14 (1.42, 3.22)	4.51 (1.11, 18.36)
65+	1.07 (0.87, 1.33)	1.12 (0.78, 1.62)	1.12 (0.13, 0.33)
Unknown	3.31 (1.53, 7.13)	2.67 (0.66, 10.72)	*
Calendar year – vs. 2017			
2018	1.43 (1.09, 1.88)	1.88 (1.13, 3.12)	0.92 (0.08, 10.79)
2019	1.38 (1.06, 1.80)	1.79 (1.09, 2.95)	2.08 (0.23, 19.13)
2020	1.46 (1.10, 1.94)	1.84 (1.04, 3.12)	0.93 (0.08, 11.33)
Model year – vs. 2017			
2018	0.92 (0.69, 1.28)	0.90 (0.65, 1.24)	0.31 (0.04, 2.78)
2019	0.94 (0.69, 1.28)	0.89 (0.52, 1.53)	*
Vehicle – vs. Honda Ridgeline			
Chevrolet Silverado 1500	1.75 (1.33, 2.29)	1.44 (0.90, 2.31)	6.91 (0.39, 122.03)
GMC Sierra 1500	1.74 (1.42, 2.13)	1.71 (1.21, 2.42)	4.16 (0.46, 37.86)
GMC Sierra 2500§	3.24 (2.13, 4.92)	3.13 (1.59, 6,19)	**

Note: For brevity, state effects not shown.
§ Effect for MY 2020 not estimated because GMC Sierra 2500 was the only MY 2020 pickup.
+ Serious/fatal injury analysis did not control for gender because all drivers in serious/fatal injury rear-end-striking crashes were male.
* Unknown driver age combined with age 65+ and MY 2019 combined with MY 2018 due to sparse data
**GMC Sierra 2500 was involved in no rear-end-striking crashes with serious/fatal injuries and was excluded from the analysis.

Table A5

Logistic regression model results of quasi-induced exposure analysis examining the odds of a rear-end-striking crash associated with FCW, by severity

Parameter	Odds ratio (95% confidence interval) All crashes (n = 1,670)	Any injuries (n = 448)	Serious or fatal injuries (n = 23)
FCW	0.96 (0.83, 1.12)	0.78 (0.61, 0.99)	0.29 (0.10, 0.82)
Driver gender – vs. female			
Male	1.32 (1.02, 1.71)	1.38 (0.91, 2.11)	0.93 (0.21, 4.18)
Unknown	0.98 (0.41, 2.37)	0.36 (0.06, 2.04)	*
Driver age – vs. 25–64			
< 25	1.88 (1.48, 2.39)	1.98 (1.40, 2.79)	4.10 (1.42, 11.83)
65+	1.09 (0.82, 1.44)	0.90 (0.56, 1.45)	1.99 (0.44, 0.05)
Unknown	1.82 (0.77, 4.28)	2.57 (0.73, 9.02)	*
Calendar year – vs. 2017			
2018	1.47 (1.09, 2.00)	1.45 (0.87, 2.41)	0.86 (0.24, 3.1)
2019	1.59 (1.18, 2.15)	1.64 (0.99, 2.70)	0.33 (0.07, 1.44)
2020	1.72 (1.26, 2.35)	1.85 (1.10, 3.10)	0.50 (0.11, 2.21)
Model year– vs. 2017			
2018	1.04 (0.88, 1.23)	1.04 (0.80, 1.35)	0.43 (0.14, 1.32)
2019	0.96 (0.79, 1.16)	0.96 (0.71, 1.29)	0.78 (0.23, 2.57)
2020	0.72 (0.32, 1.65)	0.60 (0.13, 2.72)	*
Vehicle – vs. GMC Canyon			
Chevrolet Silverado 2500 HD	1.49 (1.16, 1.91)	1.16 (0.78, 1.71)	4.38 (0.52, 37.07)
Chevrolet Silverado 3500 HD	1.92 (1.42, 2.59)	2.19 (1.40, 3.44)	10.56 (1.11, 100.93)
GMC Sierra 2500 HD	1.48 (1.14, 1.92)	1.50 (1.00, 2.25)	5.80 (0.64, 52.83)
GMC Sierra 3500 HD	2.16 (1.57, 2.97)	1.97 (1.19, 3.26)	3.24 (0.18, 57.67)

Note: For brevity, state effects not shown.
* Unknown driver age combined with age 65+ and MY 2020 combined with MY 2019 due to sparse data.

Table A6

Logistic regression analysis of the odds that rear-end-striking crash resulted in any injuries or serious/fatal injuries associated with FCW

Parameter	Odds ratio (95% confidence interval) Any injuries (n = 1,670)	Serious or fatal injuries (n = 1,670)
FCW	0.74 (0.58, 0.96)	0.25 (0.09, 0.74)
Driver gender – vs. female		
Male	0.99 (0.63, 1.56)	0.68 (0.14, 3.15)
Unknown	0.21 (0.03, 1.38)	*
Driver age – vs. 25–64		
< 25	1.16 (0.83, 1.64)	2.11 (0.74, 6.03)
65+	0.84 (0.51, 1.39)	1.98 (0.43, 9.18)
Unknown	1.98 (0.51, 7.68)	*
Calendar year – vs. 2017		
2018	1.00 (0.58, 1.75)	0.53 (0.14, 1.97)
2019	1.07 (0.62, 1.85)	0.20 (0.04, 0.90)
2020	1.14 (0.65, 2.00)	0.31 (0.07, 1.43)
Model year– vs. 2017		
2018	1.00 (0.76, 1.33)	0.40 (0.13, 1.24)
2019	1.05 (0.76, 1.44)	0.72 (0.21, 2.45)
2020	0.75 (0.15, 3.92)	*
Vehicle – vs. Chevrolet Silverado 2500 HD		
Chevrolet Silverado 3500 HD	1.68 (1.18, 2.40)	1.74 (0.56, 5.42)
GMC Canyon	1.43 (0.93, 2.19)	0.35 (0.04, 2.85)
GMC Sierra 2500 HD	1.49 (1.10, 2.02)	1.30 (0.43, 3.91)
GMC Sierra 3500 HD	1.24 (0.82, 1.88)	0.54 (0.06, 4.54)

Note: For brevity, state effects not shown.

* Unknown driver gender combined with female, unknown driver age combined with age 65+, and MY 2020 combined with MY 2019 due to sparse data.

Table A7

Logistic regression analysis of the odds that rear-end-striking crash resulted in any injuries or serious/fatal injuries associated with AEB

Parameter	Odds ratio (95% confidence interval) Any injuries (n = 1,259)	Serious or fatal injuries (n = 1,203)
AEB	0.98 (0.73, 1.31)	0.36 (0.07, 1.84)
Driver gender – vs. female		
Male	0.77 (0.52, 1.15)	+
Unknown	0.61 (0.14, 2.62)	+
Driver age – vs. 25–64		
< 25	1.04 (0.68, 1.59)	2.26 (0.56, 9.11)
65+	1.04 (0.69, 1.59)	1.00 (0.12, 8.51)
Unknown	0.65 (0.14, 2.62)	*
Calendar year – vs. 2017		
2018	1.44 (0.82, 2.54)	0.70 (0.06, 8.22)
2019	1.39 (0.80, 2.42)	1.37 (0.15, 12.68)
2020	1.34 (0.75, 2.42)	0.67 (0.06, 8.21)
Model year – vs. 2017		
2018	0.99 (0.69, 1.43)	0.36 (0.04, 3.15)
2019	0.96 (0.51, 1.78)	*
Vehicle – vs. Chevrolet Silverado 1500		
GMC Sierra 1500	1.35 (0.87, 2.08)	0.60 (0.06, 6.11)
GMC Sierra 2500§	1.35 (0.61, 2.97)	**
Honda Ridgeline	1.31 (0.77, 2.22)	0.25 (0.01, 4.30)

Note: For brevity, state effects not shown.
§ Effect for MY 2020 not estimated because GMC Sierra 2500 was the only MY 2020 pickup.
+ Serious/fatal injury analysis did not control for gender because all drivers in serious/fatal injury rear-end-striking crashes were male.
* Unknown driver age combined with age 65+ and MY 2019 combined with MY 2018 due to sparse data.
**GMC Sierra 2500 was involved in no rear-end-striking crashes with serious/fatal injuries and was excluded from the analysis.