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Intrusion and the Aggressivity of Light Duty Trucks in Side Impact Crashes

Abstract

The increase in light duty trucks (LDT) on the road in the US is a safety concern because of their aggressivity, or risk they present to occupants of cars, especially in side impacts. We use FARS data to look at fatality trends in frontal and side impacts between cars and LDT. FARS data is also used to determine risk, or fatalities per registered vehicle, imposed on car drivers from other vehicle types. We use NASS CDS data to investigate sources of serious injuries in vehicles with side impact. These sources of injury are categorized into three major groups: 1) contact without intrusion, 2) contact with intrusion, and 3) restraints. We find a greater fraction of intrusion related injuries in cars struck on their side by SUV or pick-up trucks than when they are struck by other cars.

Introduction

Over the past 25 years in the US, the number of driver deaths from side impact collisions has increased nearly 40%, while driver deaths from frontal collisions have decreased by about 20% (shown in Figure 1). This trend can partly be explained by the increasing presence of light duty trucks (LDT) on the road, primarily sport utility vehicles (SUV) and pick-up trucks (PU). In 1980 less than 20% of new vehicles sales were LDT, and currently about half of new vehicles sold in the U.S. are LDT (EPA 2005). The stiffness, frontal height and structure of SUV and PU make them especially dangerous to car occupants in near side crashes, in which the front of an SUV or PU impacts the side of the car. Research on vehicle incompatibility has primarily concentrated on frontal crashes between cars and LDT, with a few papers focusing on side impacts (SIEGEL 2001, ACIERNO 2004, and GABLER 2003). The lack of crush space available between an occupant and the impact point in a near side crash makes it difficult to design cars to

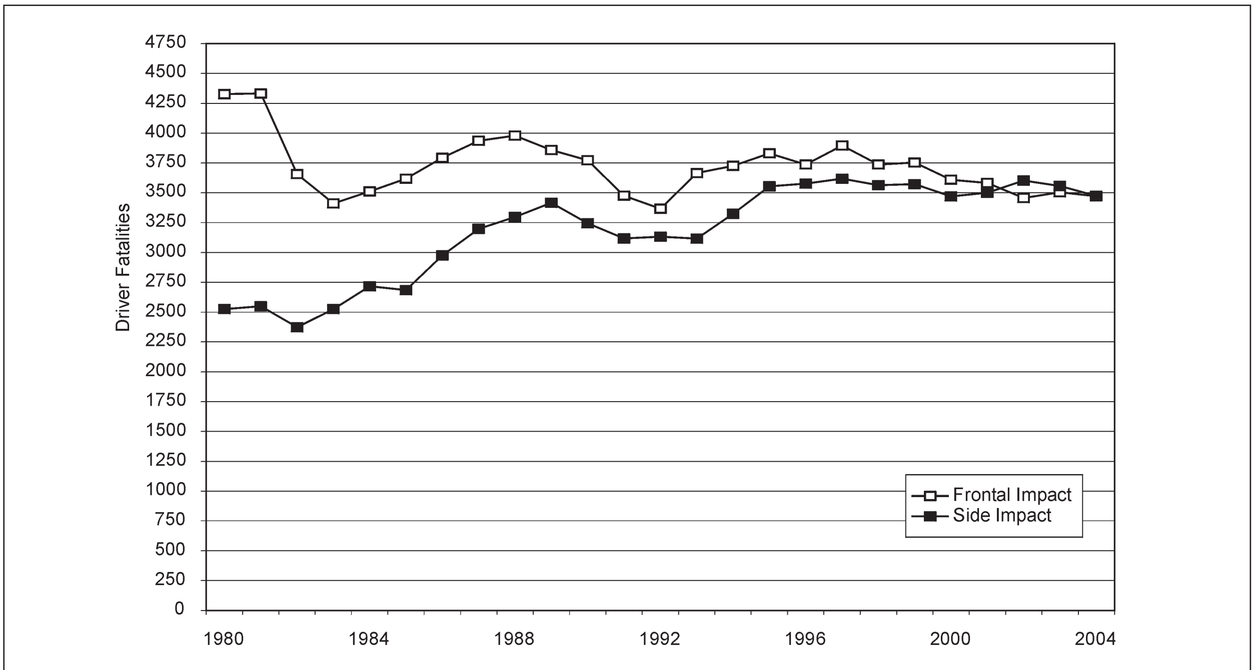

Figure 1: US driver fatalities in frontal and left side impact collisions. FARS 1980-2004

better protect their occupants. Figure 2 shows a substantial decrease in driver fatalities in car-car frontal crashes, where there is more room and structure to work with to protect occupants. Over this period, the number of cars on the road has been gradually increasing, so this decrease indicates actual safety improvements in car design and perhaps also road design.

As shown in Figure 2, driver fatalities in car-LDT side crashes have more than doubled since 1980, while a more modest increase is seen in car-LDT frontal crashes. Among car-LDT collisions, driver fatalities in side impacts exceeded the number of frontal collisions by the mid 1990s. This did not happen with either car-car or LDT-LDT collisions.

In this paper we use fatality and registration data to look at risk in cars hit on their side by other vehicles in two-vehicle crashes. We use in-depth accident investigation data to analyze the source of severe injuries in vehicles hit in side impacts and compare it to vehicles with frontal impacts. The role of intrusion is examined in these cases, including its dependence on the type of bullet, or striking, vehicle. Finally we examine the body region injured in cars hit on the driver's side by the type of bullet vehicle.

Data Sources

The two US databases used in this study are the Fatality Analysis Reporting System (FARS) and the National Automotive Sampling System Crashworthiness Data Systems (NASS CDS). FARS is a census of all motor vehicle collisions involving a death within 30 days. All of the information contained in FARS is based solely on a police accident report.

NASS CDS involves in-depth investigation of crashes, fatal and nonfatal. It contains a sample of about 5,000 police reported crashes each year, involving at least one tow-away light duty vehicle. Selection preference is given to cases with newer model year vehicles and occupants with higher severity injuries. Detailed information on all occupant injuries is obtained from medical records and interviews, and includes an Abbreviated Injury Scale (AIS) score. AIS is a system of ranking injury severity, based on threat to life, from 1 (minor injury) to 6 (maximum). Crash-investigators examine the crash scene and vehicle(s) and record vehicle damage including external crush and internal intrusion measurements. This crash investigation may take place weeks or even months after the

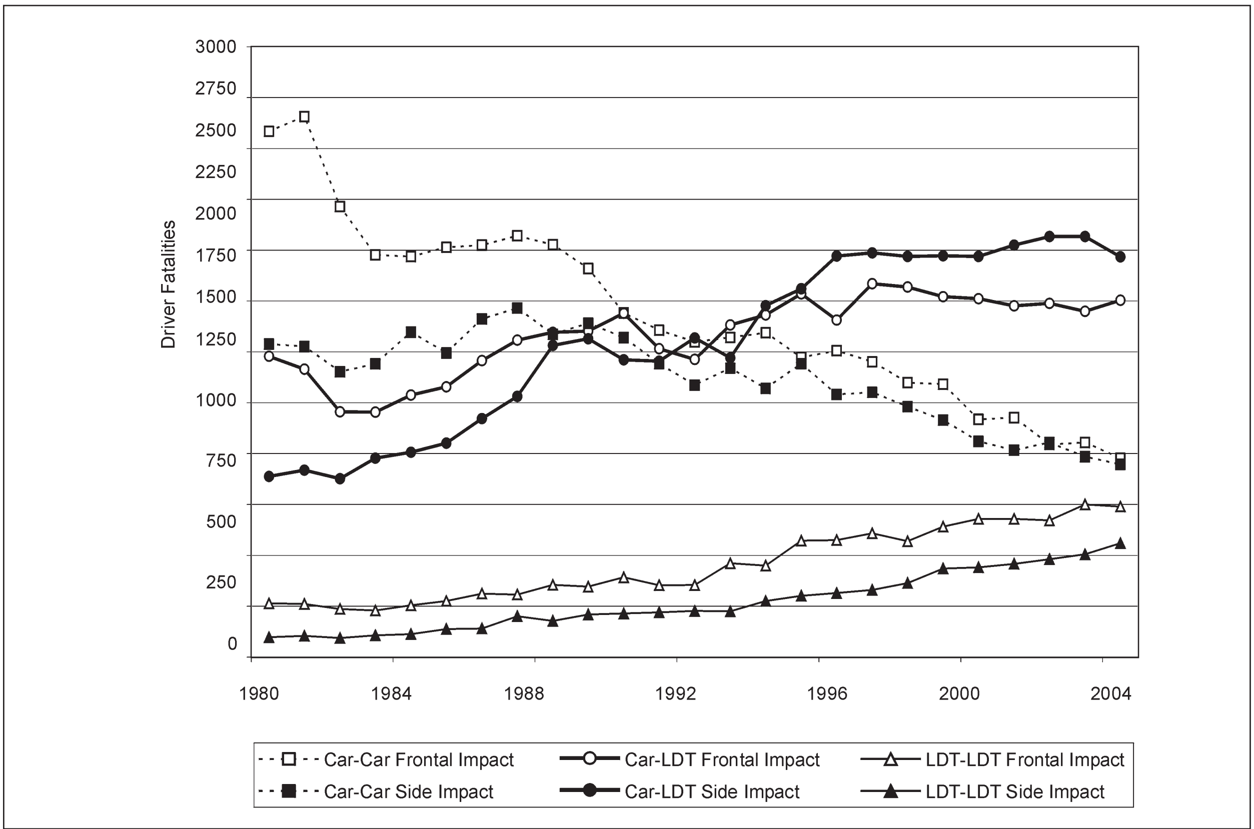

Figure 2: US driver fatalities in frontal and side impact collisions, by vehicle type. FARS 1980-2004

crash occurred. Each injury is coded to an area of the vehicle ascribed to be its source. For this study, we only list sources of injuries that have a confidence level of “certain” or “probable”. In about 10% of high severity (AIS 3-4) injuries, the source is unknown or has only a “possible” confidence level.

There are a number of different ways of counting the NASS CDS data. Each case has an accident file, vehicle files, and occupant files. Data can be counted in terms of number of collisions, number of vehicles, number of occupants injured, or number of injuries sustained. For this study, which is focused on injury causation and source, we look at the number of serious (AIS 3-6) injuries sustained by the drivers of light duty vehicles in particular crash types (frontal, side impact, one-vehicle, and two-vehicle). Drivers involved in severe collisions tend to have more than one serious injury. In an effort to reduce any double counting, we count multiple injuries to the same AIS90 body region attributed to the same source on the vehicle, as one injury. This reduces the number of injuries per driver to an average of about 1.5.

Each case in NASS CDS is assigned a weighting factor, which is claimed to be an estimate of the number of similar crashes occurring in the US that year that have not been sampled. Crashes with high severity injuries (AIS 4-6) typically have a weight of about 50, meaning that NASS CDS samples about 1 in 50 serious injury collisions. In this paper we present the “raw data”, meaning the actual number of cases investigated, as well as the “weighted data”, meaning the cases multiplied by their weighting factor. We use a cap of 500 for the weighting factor, so any cases with weights greater than 500 are set to 500. This is to ensure that extremely large weighting factors on a few cases do not skew the results. Only 1 percent of cases had weights larger than 500.

In the following analysis using NASS CDS data, we confine our study to belted drivers in vehicles model year (MY) 1997 or newer, and crash years 1997 through 2004. The bullet vehicles can be any MY. We do not include any crashes involving rollover, since the injury mechanisms for rollover are quite different than for other types of crashes. NASS CDS contains a Collision Deformation Classification (CDC) for each damaged area on the vehicle. The damaged area coded as the primary CDC is, in the investigator’s judgment, the worst damage or injury producing event, with injury taking precedence. We use the primary CDC to determine if the vehicle had a frontal or side impact.

Results

Vehicle structure

The limited amount of space between an occupant and the outer surface of the vehicle in a side impact leaves occupants more vulnerable than a head-on collision with similar severity. There is little crush space for energy absorbing structures to deform without intruding into the occupant space. Ideally, the side structure of the struck vehicle should be stiffer than the front structure of bullet vehicle, permitting the front of the bullet vehicle to absorb most of the crash energy while keeping the passenger compartments intact. Figure 3 shows the risk to car drivers when hit on the left side (8-10 o’clock) by different types of bullet vehicles. Risk here is defined as car driver deaths per million registered bullet vehicles by type. The risk from different sizes of bullet cars is roughly the same, but SUV and PU are 2 to 6 times as risky as cars are [Using fatalities per police reported crash as risk, GABLER found SUV and PU to be 5 to 7 times as risky as other cars (GABLER 2003).]. This suggests that in near-side collisions, mass is a relatively unimportant safety factor compared to the structure and stiffness of the front of the bullet vehicle. Most SUV and PU are built body-on-frame, in which the separately built passenger cabin and cargo bed are attached to a stiff chassis, causing the fronts to be very stiff and structurally inhomogeneous. This leads to less structural interaction with the opposing vehicle and more chance of intrusion into the

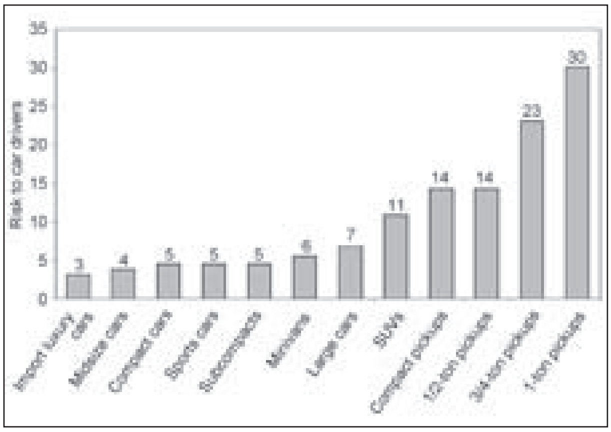

Figure 3: Risk to drivers of cars struck on the left side by other vehicles. Risk is fatalities per million registered bullet vehicle. Target car is MY 2000+. FARS and Polk data 2000-2004

opposing vehicle's passenger compartment. Their frontal height is also dangerous, especially in side impacts, since it is much higher than the door sill of a car. Using a sample of vehicle involved in side impact crashes, SIEGEL et al. find the average difference in heights of SUV/PU bumpers to the car frames is 5.7 inches (SIEGEL 2001). Because SUV and PU are structurally quite different from vans and minivans, and because the amount of NASS CDS data available on vans and minivans is so small, we leave them out of the following analysis and group together SUV and PU. Car-based or unit-body SUV have recently been adopted in some popular models, but they have relatively little influence on the data through 2004.

Causes of injury

When a vehicle crashes, one way occupants can be injured is through hard contact with an interior surface of the vehicle. This can happen, for example, if the occupant is not properly restrained or if the restraints fail to hold the occupant in position, as in side impacts where seat-belts often fail to restrain the occupant laterally. Contact with an interior surface can also occur when that surface has intruded into the passenger compartment, encroaching on the occupant's survival space. Even if there is no intrusion and the restraints prevent any hard contact, an occupant can still sustain injuries if the overall center of mass acceleration of the vehicle is too high. In these types of injuries, the restraints themselves may be listed as the source of injury. Table 1 shows these three main categories: 1) contact – non intrusion, 2) contact – intrusion, and 3) restraints, for vehicles with front damage and side damage. We only consider non-rollover crashes in the following tables.

Table 1 contrasts the main sources of injury to drivers of light duty vehicles with front damage and with side damage. Contact with intruded components is more prevalent in side (61%) than frontal impacts (35%). Restraints constitute a larger fraction of injury sources in vehicles with front (16%) versus side (4%) damage (raw data). In the case of front damage, half of injuries are associated with the steering wheel, knee bolster, or instrument panel. In side impacts, these sources account for only 6% of injuries. In vehicles with left side damage 72% of injuries are attributed to the left side, which includes the door interior and the A and B pillars; of these injuries 79% are intrusion related.

		Vehicle has front damage						Vehicle has side damage					
		Raw			Weighted			Raw			Weighted		
		Injuries	% of total		Injuries	% of total		Injuries	% of total		Injuries	% of total	
Contact – non intrusion	Front interior*	173	28%	42%	14064	31%	44%	19	4%	25%	1123	4%	24%
	Left side**	39	6%		1327	3%		65	15%		3865	15%	
	Floor	38	6%		2702	6%		15	3%		581	2%	
	Roof	9	1%		1878	4%		8	2%		422	2%	
Contact – intrusion	Front interior*	155	25%	35%	7905	17%	25%	8	2%	61%	479	2%	57%
	Left side**	17	3%		727	2%		243	57%		13591	54%	
	Floor	34	5%		2248	5%		2	0%		38	0%	
	Roof	9	1%		414	1%		8	2%		71	0%	
Restraints		102	16%		11338	25%		18	4%		2937	12%	
Other***		44	7%		2696	6%		43	10%		1850	7%	
Total		620	100%		45299	100%		429	100%		24957	100%	

* Includes steering wheel, instrument panel, knee bolster, and windshield

** Includes left side interior, A and B pillars, and left window

*** Includes fire, other occupants, loose objects, and exterior of vehicle

Table 1: Source of driver injuries. AIS 3-6 injuries in vehicles MY 1997+, non-rollover. NASS CDS 1997-2004

Intrusion

Table 2 shows the percentages of injuries coded to a component that intruded 15cm or more, in cars with front and side damage. In cars with front damage there is little difference in the fraction of intrusion related injuries resulting from other cars compared to SUV or PU (18%, 19%). However, there are significantly more intrusion injuries in left side impacts, especially when the bullet vehicle is an SUV or PU (58%) then when it is another car (35%). Intrusion injuries are 1.7 to 2.5 times more prevalent in cars hit in side impacts by an SUV or PU than by another car.

Body region

Table 3 shows body regions of car drivers injured when struck by other cars or SUV/PU, in the case of two-vehicle collisions, or in one-vehicle crashes. Cars struck by an SUV or PU are associated with more head injuries (17%) than cars struck by another car (10%), while cars struck by another car have a greater fraction of lower extremity (i.e. leg) injuries than cars struck by an SUV or PU. This result is in general agreement with the study done by SIEGEL et al. using CIREN data (SIEGEL 2001). This pattern is possibly due to the greater frontal height of the striking SUV or PU.

	bullet vehicle type			
	raw data		weighted data	
	car	SUV or PU	car	SUV or PU
Target=car with front impact (209 injuries)	18%	19%	17%	13%
Target=car with left impact (188 injuries)	35%	58%	21%	53%

Table 2: Percent of injuries associated with an intrusion. AIS 3-6 driver injuries resulting from an intrusion >15cm, listed by other vehicle type. Target vehicle is a MY 1997+ car, non-rollover. NASS CDS 1997-2004

Table 3 includes the data for cars involved in side impact one-vehicle non-rollover crashes for comparison. These crashes also cause more head injuries and less lower extremity injuries than car-car crashes, but unlike car-SUV/PU crashes they cause less thorax injuries. Note that the small sample sizes (92 car-car injures, 103 car-SUV injuries, and 116 one vehicle crashes) indicate a large amount of statistical error here.

Conclusions

Using NASS CDS data we have shown the distribution of injury sources in vehicles with side and front damage. In vehicles with front damage the sources are primarily steering wheel, knee bolster, floor and restraints. While in vehicles with side damage nearly three quarters of serious injuries come from contact with the left side interior and B pillar. Restraints play a smaller role in side impacts compared to frontal impacts. This may be an indication that seat-belts are not very effective in side impacts or that the overall center of mass acceleration is typically not high in these crashes. This may also imply that injuries resulting from side impacts are not sensitive to vehicle mass. It is clear that intrusion plays a major role in injury causation in side impacts. SUV and PU cause 20% to 30% more intrusion injuries to car drivers in side impacts than other cars do. This is likely due to the front structure of SUV and PU being too high to effectively interact with the car's frame upon impact, and the overly stiff frame rails concentrating the

	Raw data			Weighted data		
	2 vehicle crashes-bullet vehicle type		1 vehicle crashes	2 vehicle crashes-bullet vehicle type		1 vehicle crashes
Body Region	Car	SUV or PU		Car	SUV or PU	
Head	10%	17%	24%	6%	21%	19%
Face	0%	3%	1%	0%	1%	0%
Thorax	40%	45%	29%	31%	41%	26%
Abdomen	5%	10%	9%	3%	9%	9%
Spine	1%	2%	7%	1%	1%	14%
Upper Extremity	8%	4%	7%	29%	2%	9%
Lower Extremity	36%	20%	23%	30%	25%	23%
Total	100%	100%	100%	100%	100%	100%
Number of injuries	92	103	116			

Table 3: Distribution of driver injuries in side impacts. AIS 3-6 driver injuries in a car (MY 1997+) with side damage, non-rollover. NASS CDS 1997-2004

force at potentially weak areas on the target car's door.

A look at the injured body regions shows that drivers of cars hit in the side by SUV or PU have a different distribution of injuries than those drivers hit by cars in side impacts. Head injuries are somewhat more prevalent in car-SUV/PU crashes while lower extremity injuries are more prevalent in car-car crashes.

Strengthening the sides of vehicles with more rigid materials will probably reduce the number of intrusion related injuries. As pointed out by AUGENSTEIN et al., more rigid materials will limit energy absorption in a crash, resulting in greater center of mass acceleration of the vehicle and therefore the occupant. This trade off may be acceptable for reducing side impact injuries since accelerations in side impacts may not be as high as in frontal, and because there is little crush space available on the side of the vehicle. Another way to decrease side impact injuries is to improve the fronts of the bullet vehicles. Car-based SUV are becoming more prevalent and are safer to car occupants because their fronts are better at absorbing energy and they do not have the stiff frame rails present in the body-on-frame SUV and PU.

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