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Analytical observational study of nonfatal motor vehicle collisions and incidents in a light-vehicle sales and service fleet

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ABSTRACT

Motor vehicle crashes (MVCs) are a significant cause of lost-workday injuries, and consistently the leading cause of work-related fatalities in the United States for all industries combined. Prevention research has focused mainly on collisions fatal to the drivers of large trucks. This analytical observational study addresses gaps in the literature by: conducting a descriptive analysis of motor vehicle claim events involving light-vehicle drivers in a large health care industry fleet; identifying risk factors for work-related MVCs and injuries based on vehicle miles traveled; and providing details on circumstances of these events.

The study examined 8068 motor vehicle events resulting in vehicle damage, property damage, or injury reported by 6680 U.S.-based drivers in a light-vehicle sales and service fleet operated by a health care company over a 4 ½-year period (January 2010 through June 2014). Thirty-three percent (n = 2660) of the events were collisions. Collisions were segmented as recoverable or non-recoverable according to whether the company could recover costs from another party, and mileage-based collision and injury rates were calculated by gender, age, tenure, and vehicle type. Differences in collision and injury rates between groups of interest (for example, tenure and age categories) were assessed with Poisson regression techniques adjusted using generalized estimating equations (GEE) for repeated observations on the same employee over time.

Age, gender, and job tenure were significant collision risk factors, and risk patterns for recoverable and non-recoverable collisions were similar to those for total collisions. Collisions per million miles (CPMM) were significantly higher for drivers 21–24.9 years of age compared to drivers age 25–54.9 years (9.58 CPMM vs 4.96 CPMM, $p = .025$), drivers employed for less than 2 years compared to those employed 2 or more years (6.22 CPMM vs 4.82 CPMM, $p < .001$), for female drivers compared to male drivers (6.37 CPMM vs 4.16 CPMM, $p < .001$), and for drivers of passenger cars compared to all other vehicles (5.27 CPMM vs 4.48 CPMM, $p < .001$). Among collisions between the employee's vehicle and another vehicle in transport, those where the front of one vehicle hit another vehicle at an angle were the most likely to result in injury to the employee driver or another party (26%), followed by rear-end collisions (25%). Special attention should be given to preventing collisions among newly-hired employees, and to preventing angle and rear-end collisions, which were the most common types of collisions and also were most likely to result in injury than all other collisions combined.

1. Introduction

Millions of U.S. workers who drive or ride in a motor vehicle while working are at risk of being involved in a motor vehicle crash (MVC). MVCs occurring on or off a public roadway are consistently the leading cause of work-related fatalities for all industries combined. Of 66,588 work-related fatalities reported by the Census of Fatal Occupational Injuries (CFOI) between January 1, 2003 and December 31, 2015, 30% (n = 19,648) were MVCs fatal to a driver or passenger (Bureau of Labor Statistics, 2018a).[1] MVCs made up the majority of workplace fatalities

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[1] As defined by the Bureau of Labor Statistics, work-related MVCs comprise three broad categories: (1) *Roadway incidents involving a motorized land vehicle* are "events involving transportation vehicles under normal operation, on roadways, which includes the parts of the public highway, street, or road normally used for travel, as well as the shoulder or surrounding areas, telephone poles, bridge abutments, trees aligning roadway, etc.;" (2) *Non-roadway incidents involving a motorized land vehicle* "closely mirror the coding scheme for roadway incidents, but include only those instances that occur entirely off of a public roadway, such as in a field, factory, or parking lot;" and (3) *Pedestrian vehicular incidents* include "pedestrians and other nonoccupants of vehicles who are struck by vehicles or other mobile equipment in normal operation regardless of location." Pedestrian incidents are outside the scope of this paper.

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for workers employed in transportation and material moving occupations, accounting for 57% of the total in 2015. They are also a leading cause of death for occupations where driving is not the primary job duty, for example, managers and sales workers (Bureau of Labor Statistics, 2018b).

Nonfatal work-related MVCs also have substantial injury and economic consequences for workers and employers. In 2015, private-industry workers sustained an estimated 31,130 lost-workday injuries due to roadway incidents involving a motorized land vehicle and 6930 lost-workday injuries due to non-roadway incidents (Bureau of Labor Statistics, 2018c). For both roadway and non-roadway incidents, about 60% of these were serious enough to result in 6 or more lost workdays, and 33% of the total resulted in 31 or more lost workdays (Bureau of Labor Statistics, 2018c). Further, the Liberty Mutual Workplace Safety Index estimated that serious roadway incidents involving motorized land vehicles accounted for $3.7 billion in workers' compensation costs in the U.S. in 2014 (Liberty Mutual Research Institute for Safety, 2017). In 2013, a single on-the-job crash involving a nonfatal injury was estimated to cost the employer almost $65,000 on average, regardless of liability (Network of Employers for Traffic Safety, 2015).

The current study seeks to address three research gaps in the published literature on work-related MVCs: (1) the limited number of published analyses of nonfatal (as opposed to fatal) work-related MVCs; (2) the lack of research on crashes involving fleet drivers of light vehicles for whom, unlike truck drivers, driving is not the primary job duty but who nonetheless may have substantial exposure to crash risk; and (3) the lack of research on fatal or nonfatal work-related crashes involving light vehicles that assesses crash or injury risk based on actual driving exposure.

With regard to the first gap cited, the limited number of published analyses of nonfatal (as opposed to fatal) work-related MVCs, the primary national data source for nonfatal work-related injuries is the Survey of Occupational Injury and Illness (SOII), an annual survey of employers conducted by the Bureau of Labor Statistics. The SOII provides national estimates of the numbers of workers who sustain nonfatal injuries by industry, occupation, event, nature and source of injury, body part, and demographic characteristics. However, beyond describing an event in general terms (that is, as a roadway or non-roadway incident involving a motorized land vehicle, or a pedestrian struck by a motor vehicle), the SOII provides no antecedent or incident details that would help inform crash prevention activities.

With regard to the second gap noted, the vast majority of U.S. literature on work-related MVCs addresses known and hypothesized risk factors for truck drivers, including driver fatigue and hours of service [see, for example, (Blanco et al., 2011; Jovanis et al., 2011; Lemke et al., 2016; Marcus and Rosekind, 2017; McCartt et al., 2000; Pack et al., 2006)]; medical conditions [see, for example, (Birdsey et al., 2015; Hartenbaum et al., 2006; Orris et al., 2007; Sieber et al., 2014; Smolensky et al., 2011; Thiese et al., 2015; Wiegand et al., 2009)], and use of mobile devices [see, for example, (Hickman and Hanowski, 2012; Olson et al., 2009; Swedler et al., 2015)]. Few U.S. studies have been published on MVCs in non-truck driving occupations, and most of these do not examine specific risk factors for crashes. Non-truck driving populations that have been studied are law enforcement officers (Bean and Noh, 2010; Tiesman et al., 2013), workers operating agricultural equipment on public roadways (Costello et al., 2009; Gkritza et al., 2010), construction workers (Ore and Fosbroke, 1997), emergency medical services workers (CDC, 2003), workers in the mining sector (Janicak, 2011), and oil and gas extraction workers (Bell et al., 2017; Retzer et al., 2013).

The third gap addressed by this study is the lack of research that adequately estimates crash risk for workers driving light vehicles using exposure data such as vehicle miles traveled (VMT) or hours of driving (Robertson, 1998). Previous descriptive analyses, whether based on fatal or nonfatal injury data, have relied on number of persons employed (or number of full-time equivalent employees) to calculate injury or fatality rates (Chen et al., 2014; Driscoll et al., 2005; Pratt and Rodríguez-Acosta, 2013; Retzer et al., 2013). This approach does not account for the substantial differences in exposure to motor vehicle traffic across occupations and industries. The study reported here addresses this gap by using monthly mileage data linked to the driver and the vehicle to calculate incident and injury rates.

For workers whose primary job is not driving, but who use passenger vehicles for sales calls or other client contacts such as service calls, on-the-job use of motor vehicles is largely unregulated by the U.S. federal government. Parameters for managing work-related road safety are set by state traffic laws, voluntary consensus standards (ANSI/ASSE, 2017) and industry-specific guidelines (International Association of Oil and Gas Producers, 2016), and policies and procedures put in place by employers. Empirical data are needed to help organizations direct crash-prevention efforts toward the types of incidents that are most likely to result in injury, liability, and substantial damages to vehicles and other property. The objective of this study reported here was to address that need by conducting a descriptive analysis of motor vehicle claims events involving drivers in a large sales and service fleet operated by a health care company, identifying risk factors for work-related MVCs and resulting injuries and providing details on the circumstances and risk factors for these events.

2. Methods

2.1. Study design

This was an analytical observational study whereby collisions and risk factors were studied as they occurred in the workplace without manipulation by researchers. Motor vehicle collisions, including trends over time, and differences by driver demographic characteristics (age, gender, and tenure) and vehicle body type were quantified and analyzed, taking into account potential confounders.

2.2. Study population

The collaborator for this research was a company that provides health care products and services. The study population consisted of all the company's sales and service employees in the United States who drive thousands of miles each year (in all 50 states and the District of Columbia) as part of their job selling products and servicing medical devices at customer locations. To be eligible for inclusion in the study, drivers had to have been a current employee as of June 30, 2014, and drivers also must have concurred with a company privacy policy that allowed the company the use of their demographic information and driving history for research purposes. Approximately 97% of eligible drivers concurred. For the eligible drivers, data records for January 1, 2010 through June 30, 2014 were obtained retrospectively. If eligible drivers were hired after January 1, 2010, data records were obtained from their hire date through June 30, 2014. Therefore, drivers contributed for different lengths of time, which affected the number of miles each driver contributed to the data.

Sales drivers for the collaborating company chose from a range of passenger vehicles (primarily cars, crossover utility vehicles (CUVs),[2] and minivans) provided by the company for their individual use. Service drivers used company-provided vehicles for travel to client locations for servicing of medical devices. In addition to being used for

[2] A crossover utility vehicle (CUV) is a vehicle that has the larger size and practicality of a sport utility vehicle (SUV), but its ease of handling and fuel efficiency are more like that of a car. A CUV has a "unibody" construction where the body and frame are a single piece, while an SUV is assembled from a separate body and frame [Kahane, 2013. Effectiveness of pretensioners and load limiters for enhancing fatality reduction by seat belts (DOT HS 811 835). National Highway Traffic Safety Administration, Washington, DC.]

business purposes, company-provided vehicles were also available for personal use and for eligible and authorized family use. (Hereafter, these non-employees who may also be permitted to drive company-provided vehicles are referred to as “authorized drivers.”)

2.3. Ethics

This study was approved by the Institutional Review Board of the U.S. Centers for Disease Control and Prevention’s National Institute for Occupational Safety and Health (NIOSH). All records used in this study came from pre-existing databases collected and maintained by the collaborating company and its fleet safety partners for administrative purposes. To minimize the risk of loss of privacy, each driver in the study was assigned a unique, anonymous driver ID. The driver ID was created and held only by authorized personnel from the collaborating company, and never shared with NIOSH. This unique, anonymous driver ID was used in each of the data sets described in Section 2.5, Data sources.

2.4. Outcome measure

The outcome measure used in this study was collisions while the employee driver’s vehicle was “in transport,”[3] which includes the vehicle being stopped in traffic or at a traffic sign or signal. Collisions in transport included those with other motor vehicles in transport, pedestrians, animals, and fixed and non-fixed objects (for example, parked cars, telephone poles, debris in the roadway, tree limbs). Collisions both on and off the roadway were included. Off-roadway incidents included collisions in parking lots or work sites. The collisions used for the outcome measure were identified through the company’s motor vehicle claims database, as described in Section 2.5, Data sources. Other analyses subset the data to only collisions involving the employee driver’s vehicle and one or more other vehicles in transport. Incidents other than those used as the outcome measure (for example, non-collision events such as damage while parked and windshield damage only) were summarized descriptively but no rates were calculated and no statistical tests were performed.

2.5. Data sources

2.5.1. Vehicle and mileage data

Data on driving exposure were obtained from records that tracked the vehicle assigned to each employee each month and the number of miles driven by that vehicle. Vehicle mileage for a given month was based on the last odometer reading for the month as shown on fuel receipts, minus the last odometer reading for the previous month. As the vehicles were used for both business and personal travel, it was not possible to distinguish between miles driven for each purpose; thus, they are combined in this study.

If drivers changed vehicles over the course of the study, this information was captured in the data. Vehicles were coded as passenger cars or other vehicles – in this fleet, primarily CUVs and minivans – per the classification scheme used by the National Highway Traffic Safety Administration (NHTSA) to code cases in the Fatality Analysis Reporting System (National Highway Traffic Safety Administration, 2016).

2.5.2. Demographic data

A driver’s hire date and birth date were used to create values for job tenure and age. The data set included the employee’s gender. No data were available on employee race or ethnicity. Age and tenure categories were chosen based on both comparability to categories used in previously published motor vehicle literature, as well as to minimize any cells with sparse or missing data for a multivariate analysis (categories defined in Section 2.6, Data analysis).

2.5.3. Motor vehicle claims data

The company’s motor vehicle claims database was used to identify the outcome measure, collisions. This database contained any event (no exclusions) reported by an employee driver to the company’s crash management center which resulted in vehicle or property damage, a first report of injury, or any combination of these. Vehicles could be used for both business and personal travel by the employee driver and for personal travel by an authorized driver (an adult member of the household), if any. However, only claims where the employee was the driver were used in this analysis, regardless of whether these claims involved work travel or personal travel.

For each event, the motor vehicle claims data did not provide a determination of “fault” per se, thus a *Recoverability* variable present in the data for each event was used as a proxy. An event was coded as “recoverable” or “non-recoverable” according to whether or not there was a basis for the collaborating company to recover costs from another party. It is, however, important to note that “non-recoverable” events generally fell into one of two groups: those in which the employee driver’s actions overtly contributed (for example, a collision with another vehicle where the employee driver disregarded a traffic signal); and those in which there was no other party involved (for example, vehicle damage from an act of nature). Determination of injury to either the employee driver or another party was based on the employee driver’s report to the company’s crash management center.

2.5.4. Supplemental coding of motor vehicle claims data

To increase comparability to standard coding systems for MVCs, motor vehicle claims data were reviewed and manually re-coded by the NIOSH research team based on event types found in the Model Minimum Uniform Crash Criteria (MMUCC) 4th edition, a national guideline designed to generate uniform crash data for data-driven highway safety decisions within and between states and at the national level (U.S. Department of Transportation, 2012).

Events that involved a motor vehicle in transport were assigned to a *Main Type* equivalent to the MMUCC main categories for *First Harmful Event*: Non-collision; Collision with person, motor vehicle, or non-fixed object; and Collision with fixed object. Within these *Main Types*, each event was further categorized into a *Sub-type* based on the MMUCC categories found under each *First Harmful Event*. Although MMUCC is designed to be used for coding incidents which occur in traffic on public roadways, it was found to be suitable for coding similar events in the data set which occurred off public roadways.

For events involving a collision between two or more vehicles in transport, an additional MMUCC variable, *Manner of Collision/Impact*, was coded. This denotes the orientation of the two vehicles as they initially came together, for example, front to rear, angle, or sideswipe. *Manner of Collision/Impact* was coded from the perspective of the company’s vehicle, for example, a collision in which their vehicle struck the rear of another vehicle was coded as “front to rear.”

2.6. Data analysis

All datasets were merged by the unique, anonymous driver ID number. The unit of analysis was driver-month, with both collisions and total miles driven available at the monthly level. Based on previous MVC research findings, four potential risk factors present in the collaborating company’s administrative databases were examined: age, gender, job tenure, and vehicle type. Age, gender, and job tenure were found in previous studies to be risk factors for, or associated with, work-related MVCs and fatality rates (Chen et al., 2014; Driscoll et al., 2005; Janicak, 2003; Pratt and Rodríguez-Acosta, 2013; Retzer et al., 2013;

[3] The term “in transport” denotes that the motor vehicle was in operation on a roadway or in motion within or outside the trafficway. Vehicles that are stopped at a traffic sign or signal are still considered to be in transport.

Tiesman et al., 2010). Tenure is particularly relevant to studies of work-related crashes because it is directly related to employment. Of these studies, only Retzer et al., 2013 examined tenure. Vehicle type was also examined as a risk factor (Byler et al., 2016; CDC, 2011; Retzer et al., 2013).

SAS v. 9.3 software (SAS Institute, 2013) was used for management and statistical analysis of study data. Poisson regression, using PROC GENMOD, was used to analyze the data, where a count of number of collisions was related to monthly vehicle mileage as an exposure measure. Generalized estimating equations, using the REPEATED statement and an exchangeable correlation structure, were used in the Poisson regression models to account for potential within-driver correlation (repeated monthly measurements on the same driver over time) (Huang et al., 2016; Liang, 1986; SAS Institute, 2013). Demographic variables of age, gender, and tenure, and vehicle body type were each tested separately in a univariate Poisson regression analysis, then the three demographic variables were entered together in a multivariate model to test for significant covariation among the variables. These same tests of significance were also performed for age, gender, tenure, and vehicle body type by recoverability. Age was treated as a three-level variable with values of age 21–24.9 years, age 25–54.9 years, and age ≥55 years; gender was a dichotomous variable with values of male or female; and tenure was a dichotomous variable with values of < 2 years since hire date or ≥2 years since hire date. Vehicle body type was a dichotomous variable with values of passenger car or all other types.

The one exception to the use of Poisson regression for significance testing was that repeated measures analysis of variance (ANOVA), using PROC MIXED, was used to do a post-hoc test for differences in mean monthly mileage among age groups and between genders, with mileage used as a continuous variable. Repeated measures ANOVA was used to account for repeated measures of total miles driven per month for each driver in the study.

3. Results

3.1. Motor vehicle claims: collisions vs non-collisions

There was a total of 8068 auto claims filed during the 4 ½ year study period. The majority of the auto claims were non-collisions with or without the vehicle being in transport, totaling to 67% (Fig. 1). Non-collision claims tended to be events such as windshield damage, objects or stones being kicked up or thrown back while driving, hail damage, or the vehicle getting hit by a car door or shopping cart while the car was parked. Non-collisions also included much more serious events such as roll-overs and run-off-road incidents, but these were very rare in this population, with only two such events during the study period.

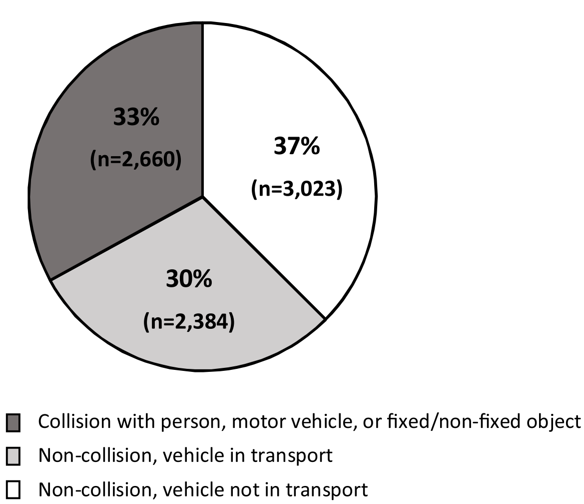

Fig. 1. Main type of auto claim incident (n = 8068).

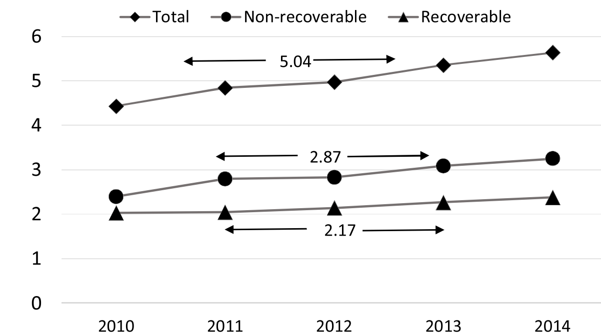

Fig. 2. Collision rates per million miles, 2010–2014, total and by recoverability.

About 33% of the claims (n = 2660) were collisions that occurred while the vehicle was in transport, which are the primary focus of this study. These included collisions with another motor vehicle, an animal, non-motorists, and objects such as telephone poles, trees, and walls.

3.2. Collisions by year

There were 6680 unique employee drivers in the data set who drove 24,411 miles a year on average. For the 4 ½-year study period, the overall rate of collisions per million miles (CPMM) was 5.04, and the rates of non-recoverable and recoverable collisions were 2.87 and 2.17, respectively (Fig. 2 and Table 1). In general, collision rates increased over the course of the study, with a significant increasing trend seen in both non-recoverable collisions (rate ratio = 1.07, $p < .001$), and in total (recoverable and non-recoverable combined) collisions (rate ratio = 1.06, $p < .001$). Although the trend in recoverable collisions increased slightly, it did not reach statistical significance (rate ratio = 1.04, $p = .063$).

3.3. Collisions by journey purpose, time of day, and day of week

Of the 2660 collisions in the data set, a total of 70.9% occurred while the vehicle was being used for work-related travel: 57.8% for business, and 13.1% for commuting to or from work. Further, 85.7% of collisions occurred Monday through Friday and 81.3% between 6 a.m. and 6 p.m. (data not shown).

3.4. Collisions by vehicle body type

Passenger cars, which accounted for 74.6% of total miles driven, had a significantly higher rate (5.27 CPMM) in comparison to all other vehicles combined (4.48 CPMM) for total collisions (Table 1) and recoverable collisions, but did not reach statistical significance for non-recoverable collisions (Table 2).

3.5. Collisions by driver demographics and recoverability

The relationships between the three key demographic variables (gender, age, tenure) and CPMM were examined in a univariate analysis, and then in a combined multivariate model.

3.5.1. Collisions by gender and recoverability

Of the 6680 drivers, 3850 (57.6%) were male. In comparison to males (4.16 CPMM), females had significantly higher rates of total collisions (6.37 CPMM) in the univariate test ($p < .001$) (Table 1). In the univariate tests by recoverability, females had significantly higher rates of both non-recoverable and recoverable collisions (Table 2). In the multivariable test, female collision rates were significantly higher than male collision rates, after adjustment for age and job tenure

Table 1
Collision frequencies and rates by driver and vehicle characteristics.

	Drivers[a]	Collisions Total	Collisions per million miles (CPMM)[b] Total	Univariate p-value	Multivariate p-value[c]
Total	6680	2660	5.04		
Gender[d]					
Male	3850	1315	4.16	–	
Female	2830	1345	**6.37*****	**< .001*****	**< .001*****
Age (years)[d]					
21-24.9	162	34	9.58		–
25-54.9	6268	2421	**4.96*****	**< .001*****	**.025*****
≥55	250	205	**5.73****	**.011****	.207
Tenure (years)[d,e]					
< 2	2824	527	6.22		–
≥2	3856	2133	**4.82*****	**< .001*****	**< .001*****
Vehicle body type[b,f]					
Passenger car	–	1981	5.27	–	
Other (mostly CUVs and minivans)	–	679	**4.48***	**< .001***	

[a] For counts, drivers were assigned to demographic categories based on the earliest month they appeared in the dataset. No drivers had missing values for any of the variables used in the analysis.

[b] *** and bold font denotes significant differences between this rate and rate for reference group, for both bivariate relationship and multivariate relationship with CPMM. **and bold font denotes significant difference between this rate and rate for reference group, for bivariate relationship with CPMM, but not multivariate relationship. *denotes significant difference between this rate and rate for reference group for bivariate relationship with CPMM (not included in multivariable model).

[c] P-values were generated from a multivariate Poisson regression analysis with gender, age, and tenure together in the model. There was no evidence found for a significant within-driver correlation, as the exchangeable working correlation matrix value was < .01.

[d] The first category presented under each group heading (Gender, Age, Tenure, Vehicle) is the baseline category to which all other categories in that group were compared in significance tests using Poisson regression analysis.

[e] The rate for tenure < 1 year was 6.73 CPMM and tenure 1- < 2 years was 5.77.

[f] Vehicle body type was tested in a univariate Poisson regression analysis, separate from the multivariate analysis of demographic variables.

(Table 1). Females also had significantly higher rates of non-recoverable and recoverable collisions than males, after adjustment for age and job tenure (Table 2).

All drivers were employees and all were over the age of 21. Drivers aged 21–24.9 years had the highest collision rates, with drivers aged 25–54.9 years and 55 years or older having significantly lower rates in the univariate test (Table 1, $p < .001$ and $p = .011$, respectively). In the multivariate analysis, drivers aged 25–54.9 years had significantly lower collision rates compared to drivers aged 21–24.9 years, but drivers 55 years or older were no longer significantly different from drivers aged 21–24.9 years. When collision rates by age were broken out by recoverability, drivers aged 21–24.9 years had the highest collision rates, with drivers aged 25–54.9 years and 55 years or older having lower rates; however, these differences did not reach statistical significance.

3.5.2. Collisions by age and recoverability

Compared to the reference group (drivers aged 21–24.9 years (9.58 CPMM)), drivers aged 25–54.9 years and 55 years or older had significantly lower rates of total collisions (4.96 CPMM and 5.73 CPMM, respectively) in the univariate test ($p < .001$ and $p = .011$, respectively) (Table 1). In the univariate test by recoverability, drivers aged 25–54.9 years and 55 years or older had significantly lower rates than drivers aged 21–24.9 years for non-recoverable collisions, but not for recoverable collisions (Table 2). In the multivariate test, total collision rates for drivers aged 25–54.9 years were significantly lower than those for drivers aged 21–24.9 years, but were no longer significant for drivers aged 55 years or older after adjustment for gender and job tenure (Table 1). In the multivariable tests by recoverability, no significant differences by age were found after adjustment for age and job tenure (Table 2).

3.5.3. Collisions by job tenure and recoverability

Compared to the reference group (drivers with less than 2 years job tenure (6.22 CPMM)), drivers with 2 or more years tenure had significantly lower rates of total collisions (4.82) in the univariate test ($p < .001$) (Table 1). In the univariate test by recoverability, drivers with 2 or more years tenure again had significantly lower rates of both non-recoverable and recoverable collisions compared to drivers with less than 2 years tenure ($p < .001$) (Table 2). In the multivariable test, total collision rates for drivers with 2 or more years tenure were significantly lower than rates for drivers with less than 2 years tenure after adjustment for age and gender ($p < .001$) (Table 1). Drivers with 2 or more years tenure also had significantly lower rates of non-recoverable and recoverable collisions than drivers with less than 2 years tenure after adjustment for age and gender ($p < .001$ and $p = .001$, respectively) (Table 2).

3.5.4. Monthly driving patterns by gender and age

To supplement collision rates, monthly driving patterns were examined by gender and age (Table 3). Male drivers drove an average of 2163 miles per month, and female drivers drove 1868 miles, which was significantly fewer miles per month on average than males. Drivers aged 21–24.9 years drove an average of 1888 miles per month, below the overall fleet average of 2034 miles per month, which was significantly fewer miles per month on average than drivers in the older age categories (Table 3).

3.6. Collisions with injuries

After collision risk factors were examined, collisions which resulted in injuries to either the employee driver or any other person were summarized. Of the 2660 collisions while the motor vehicle was in transport, 63% ($n = 1686$) were a collision with another motor vehicle also in transport, with all other types of collisions ($n = 974$) making up the remaining 37%. All other types of collisions were primarily between the employee driver's vehicle and a fixed object such as a telephone pole or mailbox, or a non-fixed object such as debris in the road. Twenty-one percent of collisions between motor vehicles in transport resulted in injury to any person, and 16% resulted in injury to the employee driver. In comparison, 2% of all other types of collisions resulted in injury to any person, and 1% in injury to the employee driver (Table 4).

Of the 1686 collisions between motor vehicles in transport, two manners of collision (that is, the orientation of the vehicles as they initially came together) stood out because they were fairly common and had a high percentage of injuries (Table 5). The first type was angle collisions, where the front of a vehicle struck the side of another vehicle. These often occurred when a vehicle was making a left turn against oncoming traffic or merging into moving traffic. Twenty-six percent of these collisions resulted in injury to any party, and 23% in injury to the employee driver. The second type was rear-end collisions, which accounted for 58% of the 1686 collisions between motor vehicles. Twenty-five percent of these resulted in injury to any party, and 20% in injury to the employee driver.

Compared to angle and rear-end collisions, all other manners of collision had overall lower percentages of collisions: 9% to any party and 7% to the employee driver. The majority of these involved backing, or a sideswipe in the same direction. However, this group also included

Table 2
Collision frequencies and rates by driver and vehicle characteristics and recoverability.

Collisions					Collisions per million miles (CPMM)[b]					
	Drivers[a]	Total	Non-recoverable	Recoverable	Non-recoverable	Univariate p-value	Multivariate p-value[c]	Recoverable	Univariate p-value	Multivariate p-value[c]
Total	6680	2660	1515	1145	2.87			2.17		
Gender[d]										
Male	3850	1315	745	570	2.36	–	–	1.80	–	–
Female	2830	1345	770	575	**3.65**	< **.001*****	< **.001*****	2.72	< **.001*****	< **.001*****
Age (years)[d]										
21-24.9	162	34	19	15	5.35	–	–	4.23	–	–
25-54.9	6268	2421	1386	1035	2.84	**.010****	0.114	2.12	0.10	0.081
≥55	250	205	110	95	3.08	**.037****	0.286	2.66	0.104	0.428
Tenure (years)[d]										
< 2	2824	527	305	222	3.60	–	–	2.62	–	–
≥2	3856	2133	1210	923	2.73	< **.001*****	< **.001*****	2.08	**0.002*****	**0.001*****
Vehicle body type[b,e]										
Passenger car	–	1981	1112	869	2.96	–		2.31	–	
Other (mostly CUVs and minivans)	–	679	403	276	2.66	.085		1.82	< **.001***	

[a] For counts, drivers were assigned to demographic variables based on the earliest month they appeared in the dataset. No drivers had missing values for any of the variables used in the analysis.
[b] *** and bold font denotes significant differences between this rate and rate for reference group, for both bivariate relationship and multivariate relationship with CPMM. ** and bold font denotes significant difference between this rate and rate for reference group, for bivariate relationship with CPMM, but not multivariate relationship. * denotes significant difference between this rate and rate for reference group for bivariate relationship with CPMM (not included in multivariable model).
[c] P-values were generated from a multivariate Poisson regression analysis with gender, age, and tenure together in the model. There was no evidence found for a significant within-driver correlation, as the exchangeable working correlation matrix value was < .01.
[d] The first category presented under each group heading (Gender, Age, Tenure, Vehicle) is the baseline category to which all other categories in that group were compared in significance tests using Poisson regression analysis.
[e] Vehicle body type was tested in a univariate Poisson regression analysis, separate from the multivariate analysis of demographic variables.

the type of collision with the highest risk of injury: front-to-front or head-on collisions. Although these were rare occurrences, with only 14 during the 4 ½-year period, 43% resulted in injury, all of which were injuries to the employee driver (n = 6).

For both non-recoverable and recoverable collisions, angle and rear-end collisions had a higher percentage of collisions resulting in injury to any person (26% and 25%, respectively) as compared to all other manners of collision combined (9%). For angle collisions, percentages resulting in injury were similar by recoverability, with 25% of non-recoverable collisions resulting in injury and 27% of recoverable collisions resulting in injury. Results for rear-end collisions, however, differed by recoverability. Among non-recoverable rear-end collisions, 13% resulted in injury to any person and 7% in injury to the employee driver. Among recoverable rear-end collisions, however, 31% resulted in injury to any person and 26% in injury to the employee driver.

4. Discussion

This large study of sales and service drivers employed by a health care company adds to the literature by beginning to fill the substantial gap in analyses of nonfatal MVCs among fleet drivers of light vehicles for whom driving is not their primary job duty. VMT-based collision rates were calculated by gender, age, job tenure, and vehicle type, as well as according to whether costs were deemed to be recoverable through another party's insurance.

This study found significantly higher collision rates for females in univariate analyses for total collisions and by recoverability. These findings persisted in a multivariate analysis that controlled for age and tenure, regardless of recoverability. The findings are inconsistent with crash data by gender for the general population, where males have higher rates of involvement in all types of MVCs: 3 times the rate of involvement in fatal crashes, 1.3 times the rate of involvement in injury crashes, and 1.4 times the rate of involvement in property-damage-only crashes (National Highway Traffic Safety Administration, 2017). Crash involvement rates by gender for the general population are calculated per 100,000 licensed drivers instead of the more precise VMT data available for this study.

The finding that females had significantly higher collision rates than males is also inconsistent with a number of other studies of work-related crashes, which reported significantly higher likelihood of fatality or serious injury for males (Boufous and Williamson, 2009; Driscoll et al., 2005; Pratt and Rodríguez-Acosta, 2013; Sultana et al., 2007; Tiesman et al., 2010). However, these studies vary in their scope and methodology, limiting direct comparison to our results. First, some studies focused only on MVC fatalities (Driscoll et al., 2005; Pratt and Rodríguez-Acosta, 2013; Tiesman et al., 2010), whereas our study

Table 3
Average monthly vehicle mileage by age group and gender.

Age (years)[a]	Average monthly mileage	p-value[b]	Gender[c]	Average monthly mileage	p-value[b]
21-24.9	1888.1	–	Male	2162.6	–
25-54.9	2037.6	< **.001**	Female	1868.3	< **.0001**
≥55	2004.7	< **.001**			

[a] Age 21–24.9 years is the baseline category to which all other age categories were compared in significance tests.
[b] Significant differences between average monthly mileage for each group compared to baseline group. Repeated measures analysis of variance was used to test for differences between group means.
[c] Male is the baseline category to which female was compared in significance tests.

Table 4
Collisions resulting in injury, by collision type.

Collision type	All collisions (# and %)		Collisions with injury to any person (# and %)		Collisions with injury to the employee driver (# and %)	
Between motor vehicles in transport	1686	(63%)	345	(21%)	276	(16%)
All other (mostly fixed/non-fixed objects)	974	(37%)	20	(2%)	12	(1%)
Total	2660	(100%)				

examined nonfatal MVCs. Second, although another of these studies did focus on nonfatal MVCs, it reported rates of crash-related injuries paid by workers' compensation (Sultana et al., 2007), not overall collision rates as were reported in our study. Third, some studies included all workers in the denominators used to calculate rates, regardless of exposure to traffic hazards at work (Driscoll et al., 2005; Pratt and Rodríguez-Acosta, 2013; Retzer et al., 2013; Tiesman et al., 2010).

One reason for the unexpected finding of higher collision rates for females may be that unlike most other studies to date, the measure of exposure used in our study was monthly VMT data, a more precise measure than the number of vehicles in a company fleet or the number of workers. Many other studies have used number of workers as the measure of exposure. An employment-based denominator assumes equal driving exposure across all segments of the workforce, which may not actually be the case (or it may include workers with no driving exposure at all) (Morris, 2015). Indeed, in our study, we found that female employees drove significantly fewer miles a year than male drivers, supporting the idea that an employment-based denominator may be an inaccurate representation of driving exposure. This study did not collect information on factors related to driving distance. Factors that could potentially affect driving distance beyond age and gender are differences in territory size, familiarity with routes, rural vs. urban territories, workload, or occupation.

The findings from this study also differ from other studies of fatal work-related MVCs by age, which report the lowest rates among the youngest workers and the highest rates among the oldest workers (Chen et al., 2014; Driscoll et al., 2005; Janicak, 2003; Pratt and Rodríguez-Acosta, 2013; Tiesman et al., 2010). These studies are not directly comparable to our results in that most included only fatal MVCs and used employment-based denominators (that is, denominators based on the total number of workers rather than exposure to traffic hazards).

In the multivariate analysis that controlled for gender and tenure, the youngest age group (21–24.9 years) still had significantly higher collision rates in comparison to drivers 25–54.9 years of age. However, drivers age 55 years or older no longer were significantly different from the youngest drivers. When divided by recoverability, the differences in collision rates among the age groups did not reach statistical significance.

The primary reason for the discrepancy between our findings by age and the existing literature again may be that unlike most other studies to date, this study calculated collision rates using monthly VMT as the measure of driving exposure, in contrast to other studies of work-related crashes that used number of workers as the measure of exposure. In our population, drivers 21–24.9 years of age drove significantly fewer miles each year in comparison to older drivers.

Univariate analysis of collision rates by job tenure, as well as multivariate analysis that adjusted for age and gender, showed that drivers employed for less than 2 years with the company had significantly higher collision rates than drivers employed for longer periods. These findings are consistent with a study of workers in the oil and gas extraction industry who died in work-related MVCs (Retzer et al., 2013): of the 60% of fatalities for whom tenure was reported, 52% had less than 1 year tenure and another 20% had 1–3 years tenure. Together, these findings support the value of crash-prevention efforts targeted to the newest employee drivers. Further, they suggest practical actions that employers can apply equally, regardless of employees' age, race, or gender.

Collision rates for passenger cars were significantly higher than for all other vehicle types. The data set for this study had no information on the type of vehicle(s) that struck or were struck by the employee driver's vehicle, so it was not possible to assess the implications of differences in vehicle type or size for individual collisions. The findings for total collisions and recoverable collisions are consistent with crash involvement rates for the general population, which are higher for passenger cars than for light trucks (a category where national data include both utility vehicles and vans). Based on VMT, in 2015, passenger cars were 1.4 times as likely as light trucks to be involved in an injury-producing crash, and 1.3 times as likely to be involved in a property-damage-only crash (National Highway Traffic Safety Administration, 2017). When total collisions were subdivided by recoverability, there were no significant differences in the rates of non-recoverable collisions by vehicle type.

This study identified the manners of collision most often associated with injury to the employee driver or another person. High proportions of angle collisions resulted in injury to the employee driver or another person. Analyses of these crashes for the general population show that angle collisions are associated with high likelihood of severe injury or fatality, particularly side-impact crashes with contact between vehicles

Table 5
Key outcome variables by detailed collision type[a] and recoverability for collisions between the employee driver's vehicle and another motor vehicle in transport (n = 1686).

Manner of collision	All collisions (# and %)		Collisions with injury to any person (# and %)		Collisions with injury to the employee driver (# and %)	
Total						
Angle (front to side)	200	12%	52/200	26%	46/200	23%
Rear-end (front to rear)	975	58%	247/975	25%	194/975	20%
All other[b]	511	30%	46/511	9%	36/511	7%
Non-recoverable						
Angle (front to side)	72	13%	18/72	25%	17/72	24%
Rear-end (front to rear)	323	56%	43/323	13%	22/323	7%
All other[b]	179	31%	6/179	3%	4/179	2%
Recoverable						
Angle (front to side)	128	12%	34/128	27%	29/128	23%
Rear-end (front to rear)	652	59%	204/652	31%	172/652	26%
All other[b]	332	30%	40/332	12%	32/332	10%

[a] Combines main event type, sub-type, and manner of collision.
[b] For example, backing collisions, sideswipes in the same or opposite direction, head-on collisions.

at the 3 o'clock or 9 o'clock positions (that is, at a right angle) (Laberge-Nadeau et al., 2008). Further, an in-depth analysis of intersection-related crashes reported that for 60% of crashes, the critical event was a left-turn error (Choi, 2010). Based on these findings, companies should consider advising employees to avoid left turns when possible, incorporating this into routing practices for drivers with regular routes.

Rear-end collisions accounted for greater numbers of injuries than any other collision type, and had overall injury likelihood similar to that for angle collisions. However, unlike angle collisions, which had similar proportions of injury-producing collisions regardless of recoverability, recoverable rear-end collisions were more than twice as likely to result in injury as non-recoverable rear-end collisions. This difference may be attributed to vehicle position in the collision. By definition, a recoverable rear-end collision would have been one in which the company vehicle was struck by the vehicle behind it; in this scenario, it is unlikely that the employee driver bore primary responsibility for the collision. However, in these types of collisions it is the occupant of the leading vehicle who is more severely injured (Khattak, 2001), hence the greater concentration of injuries among employee drivers.

To prevent angle and rear-end collisions, which were the most likely to result in injury, employers could consider offering training to help drivers recognize precursors to these crash scenarios and apply preventive strategies. They may also consider selecting vehicles with safety features such as lane departure warning and forward collision warning with automatic emergency braking.

Risk patterns by demographic factors for non-recoverable and recoverable collisions were similar to those for total collisions. Despite this finding, it is possible that companies may place greater emphasis on prevention of non-recoverable collisions because these would be associated with higher direct costs and potential liability in cases of third-party involvement. In this study, 57% of the collisions where the employee driver's vehicle was in transport (1515 of 2660) were non-recoverable. In these cases, future collisions may be avoided through interventions such as company policies to mitigate distracted, fatigued, and impaired driving; driver training; and checking motor vehicle records regularly to ensure that the employee is maintaining a safe driving record on and off the job (ANSI/ASSE, 2017; Pratt and Rodríguez-Acosta, 2015).

Further examination of recoverable collisions is warranted, particularly angle and rear-end collisions, both of which had high percentages resulting in injury compared to other manners of collision. Recoverable rear-end crashes were found to be much more likely to result in injury to the employee driver than were similar non-recoverable events. Data available for this study did not provide demographic information about the other parties responsible for recoverable collisions; however, a better understanding of recoverable collisions will offer employers the opportunity to avoid similar events in the future or reduce their severity. For example, training in defensive driving is intended not only to prevent crashes that may result from the trainee's actions; it is also intended to teach that individual how to avoid being involved in a crash due to the actions of other motorists (Lund and Williams, 1985). For both recoverable and non-recoverable collisions, employer policies requiring the use of seat belts in all seating positions can help reduce the severity of crashes that do occur (Kahane, 2015; National Highway Traffic Safety Administration, 1984).

This research has several limitations. First, it is not known how generalizable these findings are to other driver populations. However, although the analysis focused on one specific fleet, due to that fleet's large size and national distribution, the results may be applicable to many classes of drivers of light vehicles. Further, these fleet drivers worked in different driving environments; some used the vehicle for sales calls across a wide geographic area, others for service calls, and others only for short trips to local clients or the airport.

The use of first report of injury, generally by the employee, as the proxy for injury is another limitation; some initial reports of injury may have been incorrect, and in other cases an injury may have become apparent only after the first report. The lack of data on nature of injury or injury severity is another limitation. Cost data were not incorporated into this study, as the data available to researchers were limited to vehicle repair or replacement costs associated with the company's vehicle, with no information on medical or liability costs.

In addition, event data were coded from the perspective of the employee driver only. Self-report of risk factors by the employee driver may have omitted certain behavioral risk factors that might have been identified in a police investigation, for example, driver fatigue or mobile phone use. However, each collision was assessed as to recoverability, that is, whether or not costs for a claim could be recovered from another involved party because the other party's actions caused the loss. The data set reflects a final determination of recoverability; therefore, we can be confident about the contribution of the employee driver's actions or another party's actions to the incident.

Further, mileage in this study was based on driving done for business and personal use by the employee, but it may also have included mileage logged for personal travel by an authorized driver of the vehicle. We were unable to separate miles driven per month by driver (employee vs. authorized driver) or trip purpose. Therefore, the denominator might be slightly inflated for assessment of employee risk, thus making rates presented in this paper an underestimate by an unknown degree. However, we were able to demonstrate that a large majority of claims were associated with business use or commuting, and were incurred on Monday through Friday and between 6 a.m. and 6 p.m. Further, although the collaborating company manages and is responsible for all claims associated with the vehicle (regardless of whether an employee or authorized driver was driving, or whether the driving was for work-related or personal use), only claims incurred while the employee was driving were used in this analysis.

5. Conclusions

This study led to development of a complex data set for a large corporate fleet using inputs from multiple administrative sources. The result was a detailed observational analysis of nonfatal work-related motor vehicle events, rare in the peer-reviewed literature. To enhance compatibility of the current study findings with national crash data, event data were coded using the coding scheme recommended for police crash reports, and vehicle types were coded using NHTSA coding schemes.

This research addressed gaps in the literature by examining risk for non-fatal work-related collisions, whereas most previous research has focused on fatal MVCs. In addition, it used light-vehicle fleet drivers as the study population, a group of occupational drivers not widely addressed by other studies. Finally, this study calculated collision risk based on actual vehicle miles driven, which is preferable to using the number of employees as an exposure measure. The findings suggest a need for future research to further explore crash risk for female light-vehicle drivers, and both younger and newer employee drivers. In addition, the findings on collisions between vehicles confirm the need to continue to apply recognized strategies to prevent these events. Particular attention should be given to prevention of angle and rear-end collisions, which in our study were associated with high numbers and likelihood of injury. Training and vehicle selection policies may help to prevent these types of collisions.

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Conflicts of interest

The authors report no conflicts of interest.

Disclaimer

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