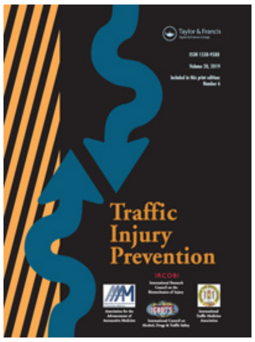

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Trends and patterns in fatal US motorcycle crashes, 2000–2016

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ABSTRACT

Objective: To investigate trends of motorcyclist fatalities and identify at-risk populations by motorcyclist demographics and crash characteristics.

Methods: We used the Fatality Analysis Reporting System (FARS) database (2000–2016) to track fatality rate trends, which were quantified by using Poisson mixed-effects regression models comparing 2000–2001 and 2007–2008, as well as 2009–2010 and 2015–2016.

Results: The overall fatality rate per 100,000 population increased from 2000 to 2016, defined by two trend lines—before and after the economic recession in 2008–2009. The overall fatality rate ratio between 2000–2001 and 2007–2008 was 1.60 [95% Confidence Interval (CI): 1.51–1.70], and between 2009–2010 and 2015–2016 was 1.09 (95% CI: 1.02–1.18). Fatality rates increased among all age groups, particularly for motorcyclists aged 60 and older. Those aged 18–29 had the highest fatality rates overall. Age-and-sex standardized state fatality rates were consistently highest in Wyoming, South Dakota, and South Carolina and lowest in Massachusetts, New York and New Jersey.

Conclusion: Motorcycle fatality rates increased overall and across all age groups between 2000 and 2016. Fatalities for the oldest riders showed the steadiest increasing trends. Results highlight the continued public health burden of motorcyclist fatalities and, by extension, the importance of improving motorcycle safety.

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Motorcycle; fatality; trends; age

Introduction

According to the Centers for Disease Control and Prevention (CDC), motor vehicles remain one of the leading causes of unintentional injury deaths in the US, affecting 38,748 individuals in 2016 (CDC 2016), thus representing a serious public health concern. During 2016, motorcycles represented 3% of registered vehicles, but motorcyclists accounted for more than 14% of all traffic fatalities (Federal Highway Administration (FHWA) 2001–2017; National Highway Traffic Safety Administration (NHTSA) 2018a). Based on estimated vehicle miles traveled (VMT), motorcyclists died nearly 28 times more often than car occupants (NHTSA 2018b). Due to the more exposed nature in the design of the motorcycle as compared to a passenger vehicle, a motorcyclist is more susceptible to fatal and life-threatening injuries in a crash (Islam and Brown 2017).

Since 2000, the number of registered motorcycles has more than doubled from 4.3 million to 8.8 million in 2016 (FHWA 2001–2017). Simultaneously, there has also been an upward trend in motorcyclist fatalities since 1994 (Powell 2018). Motorcyclist fatalities increased for both sexes from 1995–2004, particularly for females whose fatalities more than doubled and accounted for 11% of all motorcycle fatalities by 2004 (Shankar and Varghese 2006). Shankar and Varghese (2006) also illustrated shifting age trends, with an increase in the number of fatalities for those 40 and older. Given the increasing numbers of motorcycle fatalities in recent years, it is important to better understand the epidemiologic patterns of motorcycle fatalities and identify the at-risk subpopulations. The primary purpose of this study was to investigate trends in fatal motorcycle crashes from 2000–2016 and identify the risk factors associated with motorcyclist fatalities by demographic and crash characteristics (i.e. speeding, urban/rural).

Methods

Data sources

We obtained data for 2000–2016 from the NHTSA's Fatality Analysis Reporting System (FARS), which is a publicly-available annual census of police-reported fatal traffic crashes occurring on public roadways in the US. FARS contains detailed information about the crashes, vehicles, and people involved

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(NHTSA 2017). Analysis was limited to motorcycles based on FARS definitions of vehicular body type, which included motorcycles (94.8%), moped/motorized bicycles (1.9%), and other body types (3.3%). Due to state and time differences in licensure requirements, we excluded motorcyclists less than 18 years of age (n = 1,137) when examining trends stratified by age. However, all motorcyclist fatalities regardless of age were included in all other analyses. We retrieved the population size per age, sex, and state between 2000 and 2016 from the CDC population estimates (CDC 2018) to calculate fatality rates based on counts of motorcyclist fatalities including drivers (93.3%) and passengers (6.7%). Annual state motorcycle registrations were obtained from the FHWA (Table MV1) from 2000 through 2016.

Statistical analysis

Our outcome of interest was the trend in national annual motorcyclist fatality rates (per 100,000 population), and fatality rates stratified by age group (18–29, 30–49, 50–59, and 60 years or older) and sex. We also examined trends in population-based fatality rates for all riders by urban/rural crash location, non-helmet use, and speeding motorcycle. In addition to fatality rates, we developed two individual Poisson mixed-effects regression models to obtain the fatality rate ratios for 2000–2001 to 2007–2008 and 2009–2010 to 2015–2016. The rate ratios were used to quantify the change of fatality rate over the study period. The Poisson mixed-effects models used the counts of death as the dependent variable and collision years as the independent variable (0 = 2000–2001 and 1 = 2007–2008, and 0 = 2009–2010 and 1 = 2015–2016). The offset of the model was equal to the log of the population size (using 100,000 as the unit), and the state-to-state difference was treated as a random effect. Analyses were conducted using SAS Enterprise Guide 7.1 (SAS Institute, Cary, NC), with statistical significance set at 0.05.

We assessed geographic variation by mapping state age-and-sex-standardized fatality rates (per 100,000 population), using multiyear rates (2000–2004, 2005–2009, 2010–2014, and 2015–2016) to stabilize results. Direct standardization was used to make state-based comparisons by multiplying the stratified crude rates (without multipliers) by the stratified US 2010 population groups to calculate the expected number of deaths per stratum. These were then summed by state for each time period and divided by the total US population to create the standardized rates (Appendix A). The adjusted state rates were thematically mapped using QGIS version 3.2.0 based on US Census TIGER shapefiles for state and census region boundaries.

Results

Overall, the number of motorcyclist fatalities increased by 82%, from 2,897 in 2000 to 5,287 in 2016. The increased number of fatalities primarily occurred in the first half of the study period, which experienced annual increases ranging from 2% to 14% and peaked at 5,314 fatalities in 2008 before plummeting between 2008–2009 at the time of the economic recession. From 2009–20016, the trend fluctuated between smaller-magnitude yearly gains and losses, with an overall increase of 18% primarily occurring in 2016 compared to 2009.

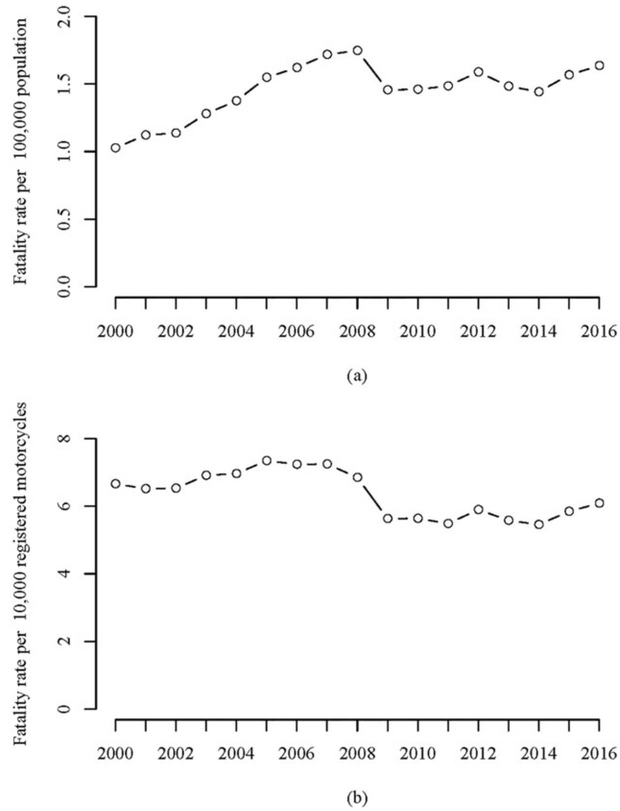

Figure 1. Annual motorcyclist fatality rates, US, 2000-2016.

Figure 1 shows the overall trend in fatality rates per 100,000 population and trends in motorcyclist fatality rates per 10,000 registered motorcycles. The trend per population was similar to that of counts (not shown), steadily increasing during the first half of the study period and fluctuating thereafter. The trend in rate per 10,000 registered motorcycles was high and relatively stable at the outset of the study period, ranging from 6.52 to 7.35 between 2000 and 2008, and did not reflect the increasing fatality counts. In 2009 the rates dropped to 5.64 and had increased to 6.09 by the end of the period.

Table 1 (2000–2001 to 2007–2008) and Table 2 (2009–2010 to 2015–2016) show the fatality counts, rates, and rate ratios (RR) with 95% CIs overall and for each of our selected variables. The overall fatality rates increased by 60% (RR: 1.60; 95% CI: 1.51–1.70) during the first half of the study, and by 9% (RR: 1.09; 95% CI: 1.02–1.18) during the latter part of the study. Although male riders accounted for more than 90% of overall deaths, female and male riders had similar rate increases until the midpoint (RR: 1.53; 95% CI: 1.38–1.69 and RR: 1.61; 95% CI: 1.51–1.71, respectively). During the latter period, changes for females were not statistically significant while male rates increased by 10% (RR: 1.01; 95% CI: 0.87–1.17 and RR: 1.10; 95% CI: 1.03–1.18, respectively). Fatality rate increases were statistically significant in all age groups during the first half of the study period, although not

Table 1. Prevalence rates (per 100,000 population) and prevalence ratios of fatally injured motorcyclists, United States, 2000–2001, 2007–2008.

	2000–2001		2007–2008		
	Count (%)	Rate	Count (%)	Rate[a]	Rate ratio[b,c] (95% CI)[d]
Overall	6,094 (100)	1.09	10,490 (100)	1.75	1.60 (1.51, 1.70)
Sex[e]					
Female	570 (11.0)	0.21	935 (8.9)	0.32	1.53 (1.38, 1.69)
Male	5,524 (90.6)	2.00	9,554 (91.1)	3.21	1.61 (1.51, 1.71)
Age (years)[e]					
18–29	1,986 (32.6)	2.04	3,041 (29.0)	2.85	1.40 (1.25, 1.56)
30–49	2,911 (47.8)	1.70	4,389 (41.8)	2.60	1.53 (1.43, 1.63)
50–59	731 (12.0)	1.19	1,901 (18.1)	2.45	2.06 (1.88, 2.26)
≥60	309 (5.1)	0.34	998 (9.5)	0.95	2.77 (2.38, 3.22)
Urban area	2,947 (48.4)	0.43	5,246 (50.0)	0.71	1.65 (1.50, 1.81)
Non-helmet use	2,767 (45.4)	0.42	4,265 (40.7)	0.60	1.43 (1.27, 1.62)
Speeding motorcycle	2,383 (39.1)	0.39	3,828 (36.5)	0.57	1.49 (1.36, 1.64)

[a]Rates are per 100,000 population.
[b]Referent group: 2000–2001.
[c]Rates and rate ratios were acquired via Poisson mixed-effects models that controlled for the random effects of every state and the fixed effects of the collision year.
[d]CI = confidence interval.
[e]The count summations are not necessarily equal to the overall counts due to missing values in FARS and some victims younger than 18 years.

Table 2. Prevalence rates (per 100,000 population) and prevalence ratios of fatally injured motorcyclists, United States, 2009–2010, 2015–2016.

	2009–2010		2015–2016		
	Count (%)	Rate	Count (%)	Rate[a]	Rate ratio[b,c] (95% CI)[d]
Overall	8,988 (100)	1.48	10,318 (100)	1.61	1.09 (1.02, 1.18)
Sex[e]					
Female	874 (9.7)	0.29	925 (9.0)	0.29	1.01 (0.87, 1.17)
Male	8,114 (90.3)	2.69	9,389 (91.0)	2.95	1.10 (1.03, 1.18)
Age (years)[e]					
18–29	2,255 (25.1)	2.00	2,867 (27.8)	2.47	1.22 (1.07, 1.40)
30–49	3,679 (40.9)	2.24	3,596 (34.9)	2.17	0.99 (0.90, 1.07)
50–59	1,869 (20.8)	2.33	2,139 (20.7)	2.55	1.09 (1.04, 1.13)
≥60	1,083 (12.0)	0.98	1,617 (15.7)	1.20	1.24 (1.15, 1.34)
Urban area	4,497 (50.0)	0.64	5,700 (55.2)	0.77	1.21 (1.05, 1.39)
Non-helmet use	3,783 (42.1)	0.49	4,035 (39.1)	0.50	1.01 (0.91, 1.14)
Speeding motorcycle	3,257 (36.2)	0.52	3,452 (33.5)	0.53	1.01 (0.92, 1.11)

[a]Rates are per 100,000 population.
[b]Referent group: 2009–2010.
[c]Rates and rate ratios were acquired via Poisson mixed-effects models that controlled for the random effects of every state and the fixed effects of the collision year.
[d]CI = confidence interval.
[e]The count summations are not necessarily equal to the overall counts due to missing values in FARS and some victims younger than 18 years.

statistically significant for those aged 30–49 during the latter period. During both time periods, the greatest increase was for motorcyclists aged 60 years or older (RR: 2.77; 95% CI: 2.38–3.22 and RR: 1.24; 95% CI: 1.15–1.34). During the first half, increases were second-highest for those aged 50–59 years (RR: 2.06; 95% CI: 1.88–2.26), while during the second half, the CI for those aged 18–29 (RR: 1.22; 95% CI: 1.07–1.40) overlapped with the CI of the oldest riders. During the first half, fatality rates for crashes that occurred in urban areas increased by 65% (RR: 1.65; 95% CI: 1.50–1.81), for non-helmeted riders by 43% (RR: 1.43; 95% CI: 1.27–1.62), and for riders of speeding motorcycles by 49% (95% CI: 1.36–1.64). During the latter period, rates increased in urban areas by 21% (RR 1.21; 95% CI: 1.05–1.39) but there was no statistically significant change for non-helmet use and speeding.

Figure 2 displays the fatality rates per 100,000 population by age group, including the overall trend as a reference. The rates for all groups increased steadily from 2000–2008 before dropping in 2009 and fluctuating thereafter. The relative amount of decline varied by age group, however. From 2009–2016 the rates fluctuated slightly but showed a gradual increase from 2014–2016. Similar trends could be observed among riders aged 18–29 years and aged 60 years or older. For riders aged 30–49, the trend was similar to overall riders between 2000 and 2008 but showed greater fluctuation from 2009 onwards, with a steep decline from 2012–2014 and a sharp increase from 2014–2016. Among riders aged 50–59 years, the fatality rate sharply increased from 2000 to 2008. Between 2009–2012, this age group had the highest fatality rate compared to other age groups until it was surpassed in 2013 by the youngest age group. When examined by sex (results not shown), males drove the overall trend. Female rates remained low but increased by 45% from 0.20 to 0.29 over the study period; female fatality counts nearly doubled from 570 to 925 during that time.

Figure 3 shows the trends in additional rider (urban crash location, non-helmet use, and speeding motorcycle) factors. Motorcyclist fatalities in urban areas continuously

Figure 2. Annual motorcyclist fatality rates by age group, US, 2000-2016.

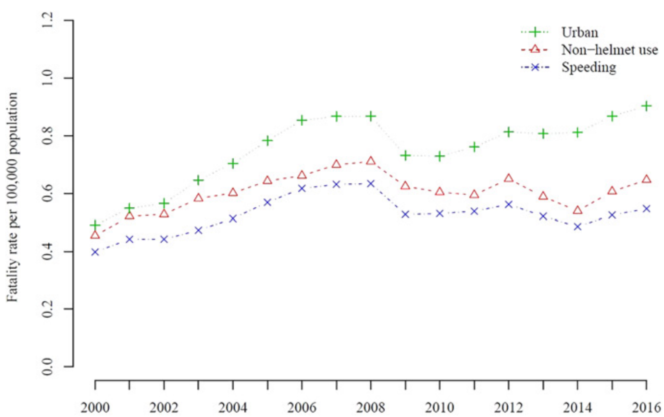

Figure 3. Annual motorcyclist fatality rates by driver and crash factors, US, 2000-2016.

increased until a marked drop in 2009; from 2010 onwards, the fatality rates again increased but not as dramatically as in the first half of the study period. The fatality rate trends among riders not using helmets and riding speeding motorcycles were similar and followed the same pattern as the overall fatality rates.

State multiyear age- and sex-standardized fatality rates (per 100,000 population) are depicted in maps in Figure 4. The widest rate range occurred in 2015–2016, with a low in Rhode Island of 0.30 and a high of 4.55 in Wyoming. Among the 5 year averages, standardized rates ranged from 0.55 (New Jersey, 2000–2004) to 3.58 (Wyoming, 2005–2009). Wyoming consistently had the highest or second-highest fatality rates across the study period, with South Dakota and South Carolina also in the top 5 during each time period. Regionally, rates were highest in the South and lowest in the Northeast with Massachusetts, New York and New Jersey consistently among the 5 states with the lowest rates during each study period.

Discussion

The objective of this study was to evaluate epidemiological trends and patterns in adult motorcycle crash fatalities in the United States from 2000–2016. Results show that the number of motorcyclist fatalities increased from 2,897 deaths in 2000 to 5,287 deaths in 2016. The overall fatality rate per 100,000 population increased across the study period, but two trend lines were apparent. During the first half of the study, the rate ratios were significant for all variables examined, but during the latter period rate ratios were lower in magnitude and were not statistically significant for females, non-helmet use, and speeding. Multiple, often inter-related factors impact motorcyclist fatalities, and additional research is needed to explore reasons for the changing trends, including economics, rider behaviors, and vehicular and environmental factors. We discuss illustrative examples of how these factors may be related to fatality trends, and refer readers to Appendix B for additional references.

Previous studies have suggested a positive association between gasoline prices and motorcycle registrations as a percent of all registered vehicles. During the early 2000s, gasoline prices were steadily increasing, as was the percentage of motorcycle registrations. The increased count and rate of motorcyclist fatalities likely reflect an overall trend in increased ridership, although the rates per population and per registered motorcycles did not correspond during the first half of the study period when ridership was rapidly increasing. The national number of registered private and commercial motorcycles doubled between 2000 (4.3 million) and 2016 (8.8 million) (FHWA 2017). Most of the increase occurred during the first half of the study period, when the number of registered motorcycles increased by 79% to reach 7.7 million by 2008 (FHWA 2017). This increase roughly mirrors the increased fatality count over the same period of time. However, unlike the fatality counts, motorcycle registrations did not drop in 2009 but continued to increase through 2012 when they plateaued with slight yearly fluctuations. Therefore, the number of registered vehicles does not fully explain the changes in motorcyclist fatalities between 2008–2016.

Motorcyclist fatality risk varies by age group. During the first half of the study, the age-group trends were relatively stable but showed more variability in the latter half of the study period. Specifically, trend lines from 2000–2008 were roughly parallel for riders aged 18–29, 30–49, and 50–59, with youngest riders having the highest rates. However, the youngest riders experienced the greatest decline at the time of the recession and were surpassed by other age groups immediately thereafter. Those aged 18–29 again had the highest rates from 2013 onwards. A previous study found a positive correlation between sales of new motorcycles with increasing gasoline prices and fatalities of riders of new motorcycles, who tended to be younger (Zhu et al. 2015). Therefore, economic factors related to ridership may, at least partially, explain the results. Additionally, younger (versus older) riders are more likely to be involved with speeding and careless, reckless or aggressive driving (Stutts et al. 2004).

The direction of fatality rate trends for motorcyclists aged 30–49, 50–59, and 60 and above were roughly similar from 2009–2016 although they differed in magnitude of change from year to year, with those aged 30–49 showing the biggest decrease from 2012–2014. Reasons for this decrease and subsequent increase during 2015–2016 are not clear. Fatality rates for motorcyclists aged 50–59 and 60 and above experienced only small declines during the recession. Overall,

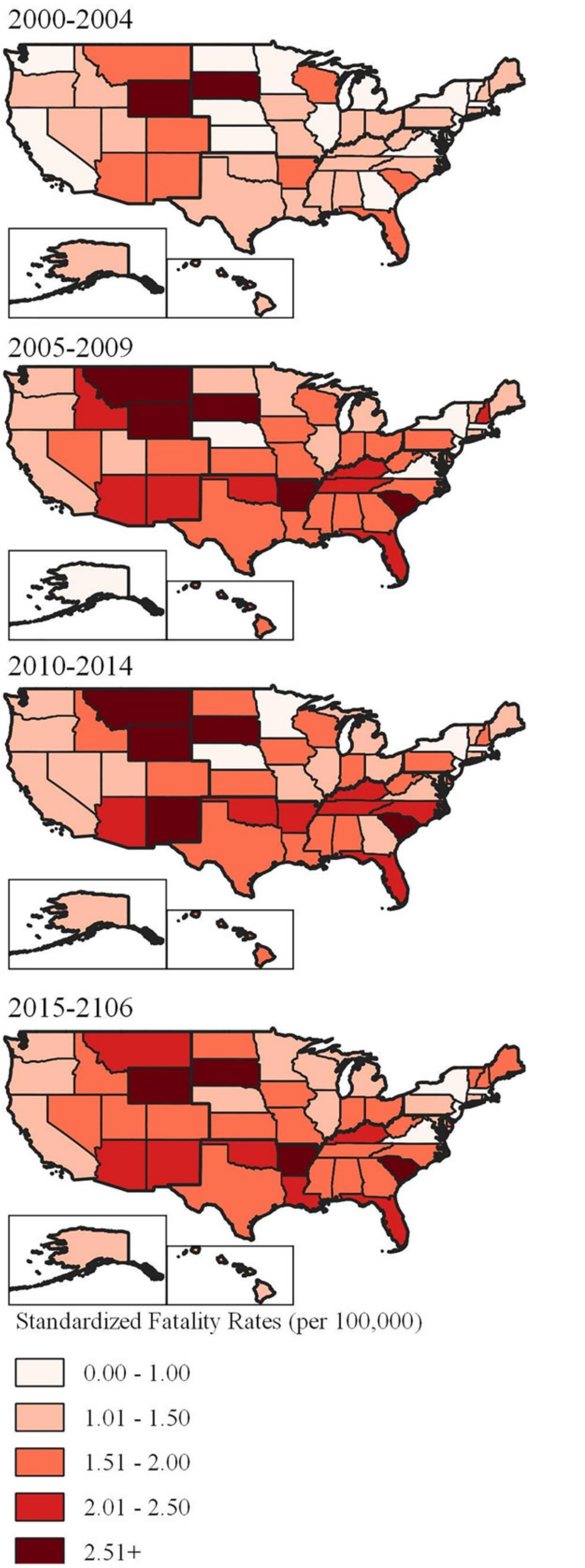

Figure 4. State age-and-sex-standardized motorcycle fatality rates per 100,000 population, 2000-2016.

fatality rates for riders in the oldest age category steadily increased across the entire period and had the largest relative increase in fatality rates across the study period for any age group. Previous studies have shown that with an increase in ridership in the older age category, there has been a rise in injuries and fatalities (Fitzpatrick and O'Neill 2017; NHTSA 2018b).

The percent of motorcycle ownership has increased among those 40 and above from 1990–2003 (Shankar and Varghese 2006). Puac-Polanco et al. (2016) suggested that there is possibly renewed riding interest for older motorcyclists as they have more disposable income. This explanation may partially account for the limited decline in oldest motorcyclist fatalities at the time of the recession. Another possible explanation for the overall increasing fatality trend among older riders is the increase in motorcycle size and power (as measured by engine displacement); older riders disproportionately ride more powerful bikes (Stutts et al. 2004). With regard to engine displacement size, however, NHTSA cautions that a causal relationship to fatality risk has not been established (NHTSA 2018b). Due to lack of variability in vehicle type, we did not include this variable in our analysis. Age has been associated with an increased odds of death which may be due, at least in part, to decreased physical resilience and decreased ability of older riders to avoid fatal crash situations (Nunn 2011). Other possible contributors to age-based differences include factors such as travel patterns (e.g. commuting versus touring), locations (e.g. urban versus rural) and risk-related behaviors (e.g. helmet use and type, speeding, alcohol use, and drug use) (Rice et al. 2017).

One difficulty in making age-based comparisons with previous studies is the general lack of defined age categories in the literature, particularly when referring to "older" riders. NHTSA publications typically use 10 year age groupings, although the lower and upper ends are not consistent. For example, a technical report used <20 and >59 (Shankar and Varghese 2006) while the Traffic Safety Facts used <30 and ≥50 (NHTSA 2018b). Another study utilizing 10 year interval groupings defined age categories as 16–24, 25–34, 35–44, and ≥45 (Stutts et al. 2004) while a study using 5 year intervals started at age 15 (Puac-Polanco et al. 2016). "Older riders" are thus variously yet broadly defined. Because our study was limited to adults, we set our youngest age category as 18–29. We combined ages 30–49 because exploratory analysis showed very similar trends within these age groups, distinct from those of other 10 year groupings.

Factors such as urban location, non-helmet use, and speeding were roughly parallel to the overall fatality rate trends for the first half of the study period, but urban crash location diverged from the other factors for the later period, as indicated by the steady upward trend in fatality rates for urban crashes. A previous study found that older motorcyclist fatalities were more likely to occur in rural areas as opposed to urban settings, while a larger percentage of younger motorcyclist fatalities involved speeding (Stutts et al. 2004). High-risk behaviors (e.g. driving under the influence of alcohol, non-helmet use, speeding, no insurance) tend to co-occur (Schneider et al. 2012; Shankar et al. 1992).

Motorcyclist fatality rates varied geographically in the United States between 2000 and 2016. Consistently throughout this time period, Wyoming, South Dakota, and South Carolina had higher fatality rates when compared to other states. Additionally, South Carolina, South Dakota, and Wyoming were among the top states for motorcyclist deaths as a percentage of all motor vehicle fatalities (Powell 2018). Massachusetts, New York and New Jersey consistently had some of the lowest fatality rates. Differences in exposure vary by state, including the number of local and tourist riders (such as those attending rallies), the length of the riding season (which is largely weather-dependent), helmet laws, and other traffic-related factors (Carter et al. 2017). An important consideration when examining difference by state is the influence of motorcycle tourism, particularly in the form of organized rallies. For example, Sturgis, South Dakota and Myrtle Beach, South Carolina draw hundreds of thousands of participants to their annual rallies. However, rallies themselves are not a sufficient explanation for state-level differences in population-based fatality rates, because other states with well-known rallies (e.g. New Hampshire, Florida) have not consistently been among the states with the highest fatality rates.

Ascertaining the traffic exposure for motorcyclists is hindered by lack of accurate data on ridership. This difficulty in determining the population at risk when computing rates is a limitation inherent in traffic injury epidemiology (Lin and Kraus 2008). Commonly used denominators include the general population, number of registered vehicles, vehicle sales, and estimated VMT. However, not everyone in the general population rides motorcycles, individuals may ride a motorcycle without being the registered owner or even licensed to operate a motorcycle, sales are not limited to new riders, and VMT may over- or underestimate actual motorcycle mileage. VMT in particular is considered to be unreliable for motorcycle travel in the United States, and registrations are expected to be higher than actual traffic exposure for motorcyclists (Samaha et al. 2007). Vehicle registration information is typically available at an aggregated state level, without stratification by age and sex. Therefore, we used population as the denominator to enable us to adjust for both age and sex. Another advantage of using population-based fatality rates is to demonstrate the public health burden of motorcyclist traffic fatalities.

This study utilized a national census of all police reported traffic fatalities with strict quality control measures including the use of trained technicians for data processing and cross-referencing of primary source materials such as hospital and medical examiner records. Another strength is the use of multiple years of data to examine trends. However, a limitation of the study is the lack of information about non-fatal crashes and resultant inability to compute the fatality rate based on total crash involvement. We included adjustment of rates to the age and sex distributions of each state to make geographical comparisons and to more accurately reflect the potential adult population at risk. Even with a less-than-ideal denominator to ascertain exposure risk, trends over time are still visible.

The results from this descriptive trend analysis highlight the continued public health burden of motorcyclist fatalities and, by extension, the importance of improving motorcycle safety. The number of fatal motorcycle crashes continues to increase, suggesting that risks for motorcyclists have not been adequately addressed over the past two decades. Among the subgroups that we analyzed, riders aged 60 and older showed steadily increasing fatality trends. Additionally, the sharp increase in fatality rates for motorcyclists aged 30–49 beginning in 2014 may require additional research and intervention focus.

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