



## Original Contribution

# Motor Vehicle Crash Injury Rates by Mode of Travel, United States: Using Exposure-Based Methods to Quantify Differences

Laurie F. Beck<sup>1</sup>, Ann M. Dellinger<sup>1</sup>, and Mary E. O'Neil<sup>2</sup>

<sup>1</sup> National Center for Injury Prevention and Control, Centers for Disease Control and Prevention, Atlanta, GA.

<sup>2</sup> Division of Statistics and Epidemiology, Research Triangle Institute, Atlanta, GA.

*Received for publication August 2, 2006; accepted for publication January 22, 2007.*

The authors used traffic exposure data to calculate exposure-based fatal and nonfatal traffic injury rates in the United States. Nationally representative data were used to identify fatal and nonfatal traffic injuries that occurred from 1999 to 2003, and the 2001 National Household Travel Survey was used to estimate traffic exposure (i.e., person-trips). Fatal and nonfatal traffic injury rates per 100 million person-trips were calculated by mode of travel, sex, and age group. The overall fatal traffic injury rate was 10.4 per 100 million person-trips. Fatal injury rates were highest for motorcyclists, pedestrians, and bicyclists. The nonfatal traffic injury rate was 754.6 per 100 million person-trips. Nonfatal injury rates were highest for motorcyclists and bicyclists. Exposure-based traffic injury rates varied by mode of travel, sex, and age group. Motorcyclists, pedestrians, and bicyclists faced increased injury risks. Males, adolescents, and the elderly were also at increased risk. Effective interventions are available and should be implemented to protect these vulnerable road users.

accidents, traffic; environment design; risk assessment

Abbreviations: FARS, Fatality Analysis Reporting System; GES, General Estimates System; NHTS, National Household Travel Survey.

Motor vehicle crashes are among the leading causes of death and disability in the United States, where more than 40,000 people are killed and millions are treated in hospital emergency departments each year (1). Injury and fatality rates vary by mode of travel. The 2004 US motor vehicle fatality rate was 14.5 per 100,000 population. The fatality rates for motor vehicle occupants, pedestrians, and bicyclists were 12.7, 1.6, and 0.3 per 100,000 population, respectively (2). These rates provide estimates of population burden, but not risk. Vehicle occupants represent a large proportion of the burden of motor vehicle crash injury overall, in part because most travel in the United States takes place in a motorized vehicle (3). Measures of exposure are needed to provide estimates of risk for a given mode of travel.

Various measures have been used to assess traffic exposure. These measures include distance traveled (2, 4–13),

number of trips taken (6, 13–16), number of streets crossed by pedestrians (17–19), and amount of time spent traveling (11, 18, 20, 21). Most of these studies have focused on a single category of road user. Few existing studies have used exposure-based rates to compare injury risks by mode of travel. Pucher and Dijkstra (6) compared injury rates among pedestrians and bicyclists in the United States, Germany, and the Netherlands. Elvik and Vaa (22) were able to compare injury risks by mode of travel in six European countries. They calculated injury rates per kilometer traveled and found that, relative to car occupants, pedestrians, bicyclists, and motorcyclists were at increased risk and bus occupants were at decreased risk.

A major limitation in estimating exposure-based traffic injury rates in the United States is the lack of readily available data on exposure. The US Department of Transportation reports annual estimates of motor vehicle miles traveled

but does not report annual estimates for nonmotorized travel (23). The same agency has conducted the National Household Travel Survey (NHTS), formerly the Nationwide Personal Transportation Survey, on a periodic basis since 1969. The NHTS provides national travel estimates for all modes, including nonmotorized travel, but this survey is conducted only every 5–6 years. The NHTS was last conducted in 2001.

We undertook a study to ascertain rates of fatal and non-fatal traffic injury by travel mode, age, and sex in the United States, using daily person-trips as the measure of exposure. To our knowledge, this is the first use of the 2001 NHTS to provide exposure-based injury rates for all major modes of travel, motorized and nonmotorized, on public roadways.

## MATERIALS AND METHODS

### Data sources

Three data sources from the US Department of Transportation were used for this analysis. Fatal injuries were identified from the Fatality Analysis Reporting System (FARS) (2). FARS is a national census of all traffic crashes on public roads in which a fatality occurred within 30 days of the crash. FARS data are abstracted from multiple sources, including police accident reports, vehicle registration files, driver licensing files, vital statistics, death certificates, and medical examiner reports. Nonfatal injuries were identified from the General Estimates System (GES), a nationally representative sample of police-reported crashes on public roads (2). All GES data are abstracted from police accident reports. FARS and GES contain only those events that involve a motor vehicle. Detailed descriptions of the FARS and GES methodologies have been published elsewhere (2). Fatal and nonfatal injuries were selected for the years 1999–2003.

The third data source was the 2001 NHTS. Travel exposure data (person-trips) were obtained from this nationally representative sample of daily and long-distance travel behaviors (24). A person-trip was defined as a one-way journey between two points. A nationally representative sample of households was selected; travel data were collected for all civilian, noninstitutionalized members of the household. Demographic information about each household member was collected during an initial telephone interview. Travel diaries were then mailed to each household, and the household was randomly assigned one day for which all members recorded their travel behaviors in their travel diaries. Information from the travel diaries was collected during a follow-up telephone interview. The overall response rate was 41 percent. Additional details about the 2001 NHTS methodology are available elsewhere (24). Person-trips were selected as the exposure measure because of concerns about the validity of self-reported data on trip distance (16, 25).

### Statistical analysis

We defined six primary travel modes: passenger vehicle (passenger car, sport utility vehicle, van, or light truck), motorcycle, walking, bicycle (includes tricycle, unicycle),

bus, and all other vehicles (e.g., large truck, motor home, taxi, limousine, hotel/airport shuttle). Although NHTS also measured travel by air, rail, and boat, these travel modes were excluded from our analysis because FARS and GES include traffic injuries that occur on public roadways only. The excluded travel modes accounted for 0.7 percent of all person-trips.

FARS and GES data were provided by the National Highway Traffic Safety Administration. Person-trip data were obtained by using the NHTS online analysis tool (available at <http://nhts.ornl.gov/index.shtml>). Sample data (i.e., GES and NHTS) were weighted to reflect the population. For each travel mode and for all modes combined, we calculated annualized fatal and nonfatal injury rates per 100 million person-trips and associated 95 percent confidence intervals. Age- and sex-specific rates were calculated overall and for each mode. Estimates and standard errors were calculated by using SAS (26) and SUDAAN (27) software. Rates and 95 percent confidence intervals were calculated in Microsoft Excel (28). The variance of the rate ( $\text{var}(r)$ ) was calculated as  $\text{var}(r) = (1/x^2) \times [\text{var}(y) + r^2 \text{var}(x)]$ , where  $r = y/x$  (29). The normal approximation was used to calculate the confidence intervals, unless the annualized number of deaths was less than 100, in which case the Gamma distribution was used (30).

Rates are not reported if the number of deaths was less than 20, the number of person-trips was less than 20, or the relative standard error was  $\geq 30.0$ . Confidence intervals were used as a conservative assessment of significance; when confidence intervals narrowly overlap, rates may in fact reach statistical significance at the  $\alpha = 0.05$  level.

## RESULTS

From the period 1999–2003, the annualized number of fatal traffic injuries was 42,132 and the annualized number of nonfatal traffic injuries was 3,048,000. The distribution of fatal and nonfatal injuries by mode of travel is shown in table 1. Passenger vehicle occupants account for the majority of both fatal and nonfatal injuries (76.6 percent and 92.0 percent, respectively). Bus occupants account for the smallest proportion of both fatal and nonfatal injuries (0.1 percent and 0.6 percent, respectively).

In 2001, an estimated 403.9 billion person-trips occurred in the United States (table 1). The two most common modes of travel were passenger vehicle (86.4 percent) and walking (8.8 percent).

Annualized fatal injury rates are presented in table 2. The overall annualized fatality rate was 10.4 per 100 million person-trips. Motorcyclists had the highest fatality rate (536.6 per 100 million person-trips), followed by other vehicle occupants (28.4 per 100 million person-trips), bicyclists (21.0 per 100 million person-trips), pedestrians (13.7 per 100 million person-trips), passenger vehicle occupants (9.2 per 100 million person-trips), and bus occupants (0.4 per 100 million person-trips). All rates are significantly different from one another in that the confidence intervals do not overlap. Males had significantly higher fatality rates than females for all modes of travel except motorcycle

**TABLE 1. Number and distribution of fatal and nonfatal injuries (1999–2003, annualized) and person-trips (2001), by mode of travel, United States\***

Mode of travel	Fatal injuries		Nonfatal injuries		Person-trips	
	No.	%	No.	%	No. (millions)	%
Passenger vehicle	32,283	76.6	2,804,000	92.0	349,125	86.4
Motorcycle	3,112	7.4	60,000	2.0	580	0.1
Walking	4,846	11.5	76,000	2.5	35,366	8.8
Bicycle	695	1.6	48,000	1.6	3,314	0.8
Bus	40	0.1	18,000	0.6	11,458	2.8
Other vehicle	1,156	2.7	42,000	1.4	4,068	1.0
Total†	42,132	100.0	3,048,000	100.0	403,912	100.0

\* Data sources: Fatality Analysis Reporting System (fatal injuries), General Estimates System (nonfatal injuries), National Household Travel Survey (person-trips).

† Totals may not equal sum of categories because of rounding.

and bus, for which no significant differences were observed (table 2). For some travel modes, fatality rates by age group were not presented because of unreliable rates. The age group 15–24 years had the highest overall and passenger

vehicle occupant fatality rates, followed by the age group  $\geq 65$  years. The age group  $\geq 65$  years had the highest fatality rates for all other modes, although this difference was significant for only pedestrian and bus travel. Where reported,

**TABLE 2. Annualized fatal injury rates per 100 million person-trips, by mode of travel, sex, and age, United States, 1999–2003\***

Person category	Passenger vehicle		Motorcycle		Walking		Bicycle	
	Rate	95% CI†	Rate	95% CI	Rate	95% CI	Rate	95% CI
Sex								
Male	12.4	12.1, 12.6	551.2	426.2, 676.2	20.3	19.3, 21.2	27.6	24.3, 31.0
Female	6.3	6.2, 6.5	434.1	234.6, 633.7	8.0	7.5, 8.5	7.2	5.7, 9.0
Age group (years)								
0–4	2.5	2.3, 2.8			6.0	4.8, 7.2		
5–14	2.8	2.6, 3.0			4.5	3.9, 5.1	9.3	7.5, 11.1
15–24	21.3	20.4, 22.1			12.4	11.0, 13.9	30.9	21.6, 40.3
25–64	7.7	7.6, 7.9	517.0	397.5, 636.5	15.7	14.9, 16.5	34.3	27.9, 40.7
≥65	15.0	14.5, 15.6			29.8	27.1, 32.5	41.7	31.8, 53.6
Total	9.2	9.1, 9.4	536.6	419.8, 653.4	13.7	13.2, 14.2	21.0	18.5, 23.4
	Bus		Other vehicle		Total			
	Rate	95% CI†	Rate	95% CI	Rate	95% CI		
Sex								
Male	0.4	0.2, 0.5	35.1	30.9, 39.2	14.6	14.4, 14.8		
Female	0.4	0.2, 0.5	10.1	7.7, 12.5	6.5	6.3, 6.6		
Age group (years)								
0–4					2.9	2.6, 3.1		
5–14			14.4	11.0, 18.5	3.0	2.9, 3.2		
15–24			28.1	17.7, 38.6	20.9	20.1, 21.7		
25–64	0.7	0.4, 1.1	30.6	26.5, 34.8	9.6	9.5, 9.8		
≥65	2.4	1.3, 4.1	43.5	27.3, 59.7	16.6	16.0, 17.1		
Total	0.4	0.3, 0.5	28.4	25.3, 31.6	10.4	10.3, 10.6		

\* Data sources: Fatality Analysis Reporting System (fatal injuries), National Household Travel Survey (person-trips).

† CI, confidence interval.

**TABLE 3. Annualized nonfatal injury rates per 100 million person-trips, by mode of travel, sex, and age, United States, 1999–2003\***

Person category	Passenger vehicle			Motorcycle		Walking		Bicycle	
	Rate	95% CI†		Rate	95% CI	Rate	95% CI	Rate	95% CI
Sex									
Male	757.4	719.2,	795.5	10,019.0	7,486.6, 12,551.5	272.7	235.6, 309.9	1,690.2	1,343.5, 2,036.9
Female	845.9	800.1,	891.7	12,874.7	6,363.5, 19,386.0	165.6	143.2, 188.0	988.7	689.3, 1,288.1
Age group (years)									
0–4	316.6	278.5,	354.7			125.3	75.0, 175.6		
5–14	453.2	411.1,	495.3			255.2	191.9, 318.4	1,075.2	814.9, 1,335.5
15–24	1,934.4	1,804.4,	2,064.6			287.3	243.7, 330.9	3,279.4	2,301.4, 4,257.5
25–64	730.0	692.7,	767.4	9,251.5	6,763.4, 11,739.7	206.1	182.8, 229.4	1,719.0	1,231.0, 2,207.0
≥65	601.7	521.6,	681.8			184.3	145.6, 223.1		
Total	803.0	763.3,	842.7	10,336.6	7,734.8, 12,938.3	215.5	187.4, 243.6	1,461.2	1,150.7, 1,771.6
	Bus			Other vehicle		Total			
	Rate	95% CI†		Rate	95% CI	Rate	95% CI		
Sex									
Male	171.1	128.2, 213.9		1,190.7	916.7, 1,464.7	742.0	704.9, 779.1		
Female	151.8	118.0, 185.7		552.4	360.3, 744.5	766.7	725.8, 807.7		
Age group									
0–4						293.1	258.7, 327.6		
5–14	99.4	69.2, 129.6				409.0	372.8, 445.3		
15–24	190.8	122.7, 258.8		1,217.6	552.4, 1,882.7	1,738.6	1,624.2, 1,853.0		
25–64	322.2	232.5, 411.9		1,157.9	915.1, 1,400.7	712.9	677.2, 748.6		
≥65	88.8	44.8, 132.8		579.7	293.2, 866.3	563.5	487.4, 639.5		
Total	160.8	126.5, 195.2		1,020.6	778.5, 1,262.8	754.6	717.9, 791.4		

\* Data sources: General Estimates System (nonfatal injuries), National Household Travel Survey (person-trips).

† CI, confidence interval.

children (aged <15 years) had the lowest fatality rates for all modes of travel, with the exception of other vehicle occupants (difference not significant).

Annualized nonfatal injury rates are presented in table 3. The overall nonfatal injury rate was 754.6 per 100 million person-trips. The highest nonfatal injury rate was for motorcyclists (10,336.6 per 100 million person-trips); the lowest nonfatal injury rates were for bus occupants (160.8 per 100 million person-trips) and pedestrians (215.5 per 100 million person-trips). No sex difference was observed regarding the overall nonfatal injury rate (table 3). However, females had higher nonfatal injury rates as passenger vehicle occupants, while males had higher rates for pedestrian, bicycle, and other vehicle travel. For some travel modes, nonfatal injury rates by age group were not presented because of unreliable rates (table 3). The age group 15–24 years had the highest nonfatal injury rate overall (1,738.6 per 100 million person-trips), as well as for passenger vehicle (1,934.4 per 100 million person-trips) and bicycle (3,279.4 per 100 million person-trips) travel. In contrast to the fatal injury rates, the age group ≥65 years had lower nonfatal injury rates than those for the age group 25–64 years both overall and for each travel mode (where reported). All rates were significantly lower for the age group ≥65 years versus 25–64 years, with the exception of pedestrian travel.

## DISCUSSION

Our findings quantify differences in traffic injury risk by mode of travel. We identified those groups that face the highest risks of traffic injury. Relative to passenger vehicle occupants, motorcyclists, bicyclists, and pedestrians are 58.3, 2.3, and 1.5 times, respectively, more likely to be fatally injured on a given trip. Bus travel is the safest travel mode, followed by passenger vehicle travel. These findings mirror the experience of European countries (22). Increased likelihood of crash involvement and increased likelihood of injury, given a crash, both contribute to the vulnerability of motorcyclists, bicyclists, and pedestrians (22). Consistent with our findings, Pucher and Dijkstra (6) reported increased risk (per kilometer traveled) for pedestrians and bicyclists, in comparison to car occupants, in the United States. They further found that the fatal and nonfatal injury rates for walking and cycling were higher in the United States than in Germany or the Netherlands, suggesting that differences in transportation environments may play a role in the safety of nonmotorized travel.

Pedestrian fatality rates per trip increased with age; studies using time spent walking as the exposure measure have also found increased risks for older pedestrians (18, 20). We found that bicyclist fatality rates per trip were higher for

males than females and for adolescents and adults than children 5–14 years of age, which is consistent with studies that used amount of time spent cycling as the primary exposure measure (21). Although children spend more time on bicycles than adults do (21), they may be less likely to travel on roads with high traffic volume or high speeds or during nighttime hours, which are more dangerous settings in which to cycle. On the basis of amount of time spent cycling, Rodgers (21) found increased bicycle fatality risk for those who rode after dark. Such differences in exposure to different traffic environments were not captured in our analysis.

In our analysis, adolescents and the elderly were found to be at increased risk of fatal traffic injuries, which is consistent with studies that have calculated death rates per vehicle mile traveled (5, 7, 8, 31). Reasons for the high occupant fatality rates observed among teen drivers include their high rates of crash involvement, whereas high case-fatality rates due to increased physical frailty among the elderly are largely responsible for the high fatality rates for this age group (7).

Per trip, males had higher fatality rates than females overall and for most modes of travel. A notable exception is bus travel, where no sex difference was observed (0.4 per 100 million trips). This is the only motorized travel mode for which most people are passengers rather than drivers and therefore do not control operation of the vehicle. For passenger vehicle occupants, males were generally involved in more lethal crashes than females, as evidenced by their higher fatality rate but lower nonfatal injury rate. Several studies have used vehicle miles traveled to examine driver risk of crash involvement. Kweon and Kockelman (5) found little gender difference in crash rates but higher injury and death rates for female drivers in many passenger vehicle types. However, after adjusting for average annual miles driven, Massie et al. (9) found that female drivers have lower crash rates, injury rates, and death rates per vehicle mile traveled.

### Public health implications

Our findings suggest that a shift from passenger vehicle travel (lower risk) to nonmotorized travel (higher risk) could result in an overall increase in the numbers of people killed in traffic. Although several studies have found that increased pedestrian and bicycle volume may reduce the risk of pedestrian or bicycle crashes (32–34), it is important to note that these studies assess an individual's risk of crash injury. In contrast, the population burden (the absolute number of pedestrians or bicyclists killed) from traffic injuries may increase because of an increase in the number of people participating in nonmotorized (higher risk) travel.

Measures that prevent crashes and injuries for pedestrians and bicyclists are needed, especially given the recent focus on increasing physical activity through active travel. The benefits of physical activity, including prevention of obesity, cardiovascular disease, diabetes, and other chronic conditions (35, 36), must be balanced against the increased injury risks for pedestrians and bicyclists traveling on roadways. Effective countermeasures for these road users include side-

walks (37, 38), bicycle lanes (39), bicycle helmets (40), reductions in vehicle speeds (41, 42), and engineering measures such as traffic signals at high-speed intersections; exclusive walk signal phasing; refuge islands and raised medians on multilane, high-traffic-volume roads; and increased intensity of roadway lighting to reduce nighttime pedestrian crashes (37, 43).

It is important to note that most bus occupants are also pedestrians during some portion of their journeys (e.g., during the trip to and from the bus stop) (44). The low injury rates observed for bus travel reflect injuries sustained during the bus trip only and do not take into account injuries that might be sustained during the trip to and from the bus stop. Measures to promote pedestrian safety should also consider the routes that provide access to public transportation.

Motorcyclists represent another group of vulnerable road users. While a very small proportion of travel in the United States occurs on motorcycle (0.1 percent of all trips), fatality and injury risks for motorcyclists far exceed those for any other category of road user. Motorcycle helmets are effective for reducing mortality (45, 46) and head injury in the event of a crash (45); however, only 58 percent of motorcycle riders in the United States wear helmets (47). Moreover, the repeal of motorcycle helmet laws in some states in recent years has contributed to a decline in helmet use and an increase in motorcycle injuries and fatalities (48–50).

### Study limitations

There were several limitations of this study. First, the data provide national estimates only. Second, the NHTS data do not provide information about the traffic environment (e.g., presence of sidewalks, travel speed) or risk and protective behaviors (e.g., safety belt use, helmet use, alcohol impairment) known to affect the likelihood of crash or injury. Third, response rates for the 2001 NHTS were low (41 percent overall); however, the analysis weights include an adjustment factor for nonresponse (24). Fourth, GES estimates may undercount the number of nonfatal traffic injuries in the United States. GES estimates, which are based on police accident reports, are consistently lower than the number of nonfatal traffic injuries estimated by hospital-based data. In 2003, the GES estimate of nonfatal traffic injuries was about 20 percent lower than the hospital-based estimate (2,889,000 vs. 3,583,216) (1, 51). Furthermore, the data include only those events that involve motor vehicle crashes on public roads. Bicyclist and pedestrian injuries that occur on public roads but do not involve a collision with a motor vehicle are not reported here. Finally, although we used 5 years of injury data to stabilize small cell sizes, we were unable to report some rates based on small numbers of deaths or trips because of concerns about the reliability of the estimates.

### Study strengths

The primary value of our study is the use of exposure data (i.e., number of trips) to assess injury risk. A core function of epidemiology is to quantify the risk of developing a specified outcome (i.e., injury or disease), given a specified

exposure. A key task in this endeavor is to determine the population at risk of developing the injury or disease (52). Use of the NHTS data to estimate traffic exposure has enabled us to identify those who are at risk (i.e., exposed to a given travel mode) and then estimate the risk of injury by mode.

These exposure-based rates have several advantages over population-based rates. First, exposure-based rates inform about the inherent risk of the exposure itself and can be directly compared to assess the relative risk of different travel modes. Second, exposure-based rates account for possible changes in exposure over time and can be helpful in assessing whether a declining trend is due to factors such as improved safety or improved trauma care following an injury (although additional information would be needed to identify the specific factor driving the trend). Trends in population-based rates do not allow one to distinguish these types of improvements from changes in amount of exposure to the risk factor.

### Concluding comments

To our knowledge, our study is the first to quantify the rates of fatal and nonfatal motor vehicle crash injuries associated with all modes of travel (motorized and nonmotorized) for all age groups and trips taken in the United States. These exposure-based risk estimates were made possible because of the NHTS, the only comprehensive source of travel behavior data in the United States. Given the uncertain funding for future NHTS surveys, it is unclear whether this type of analysis will be possible in the future.

We found that motorcyclists, pedestrians, and bicyclists face increased injury risks. Males, adolescents, and the elderly are also at increased risk of traffic injury. Effective interventions (37–43, 45, 46, 53–56) are available and should be implemented to reduce the burden of traffic injuries in the United States.

### ACKNOWLEDGMENTS

The authors acknowledge Tonja Lindsey and Fan Zhang at the National Highway Traffic Safety Administration for their assistance with the FARS and GES data.

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the Centers for Disease Control and Prevention.

Conflict of interest: none declared.

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