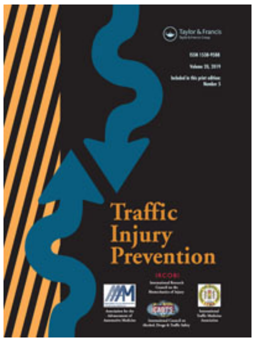

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Trends in bicycle-related injuries, hospital admissions, and deaths in the USA 1997–2013

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ABSTRACT

Objective: Cycling is associated with numerous health benefits but also the risk of traumatic injury. Recent data demonstrate an increase in overall cycling injuries as well as hospital admissions from 1997 to 2013 in the United States. We seek to better understand the causes of the increase in cycling injuries and hospital admissions.

Methods: Data regarding cycling-related injuries and hospital admissions were obtained from the National Electronic Injury Surveillance System (NEISS). Participation data were derived from the *National Sporting Goods Association Sports Participation Survey*, and fatality data were collected from the Fatality Analysis Reporting System (FARS). Population estimates were obtained using a complex survey design. Linear regression was used to evaluate univariate relationships between cycling injuries, hospital admissions, deaths, and participation. To evaluate factors associated with hospital admission, we developed a multivariable logistic regression model that included year, age, gender, body part injured, and injury type (i.e., contusion, fracture, or laceration).

Results: The number of individuals who cycle did not change significantly over time, but there was a substantial increase in cycling-related injuries, leading to an increase in per participant injuries from 701/100,000 in 1997 to 1,164/100,000 in 2013. When the injuries were evaluated by age group, younger cyclists have an increased risk for injury, whereas the rise in injuries among older cyclists stemmed from an increase in ridership rather than a unique susceptibility to injury. Trends in hospital admissions and fatalities appeared to be driven by increases in the older age groups. In the multivariable model evaluating factors related to hospital admission, the odds of hospital admission increased for each decade after age 25, as well as male gender and body part injured.

Conclusion: On a per participant basis, the rate of cycling-related injuries and hospital admissions increased between 1997 and 2013. This trend likely reflects a combination of shifting demographics among cyclists with an increase in older cyclists who are at increased risk of severe injury.

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Introduction

Riding a bicycle, whether for leisure, sport, or fitness, benefits the health of participants and society at large. As a form of nontraumatic exercise, cycling decreases the incidence of many diseases endemic to sedentary societies, including coronary artery disease (Morris et al. 1990), obesity (Wen and Rissel 2008), and diabetes (Lynch et al. 1996). Individuals who ride a bicycle regularly have lower rates of death from any cause (Andersen et al. 2000). Furthermore, those who use a bicycle for transportation could also contribute to reduced fuel consumption, carbon dioxide emissions, and road congestion.

Despite numerous health benefits, cycling can be deterred by climate considerations (Dill and Carr 2003) as well as fear of traumatic injuries (Macmillan et al. 2014). In fact, a recent study found that cycling-related injuries and hospital admissions (Sanford et al. 2015) are increasing in adults in the United States, particularly among older adults. This rise in morbidity associated with cycling warrants further investigation. Our objective is to better understand the factors contributing to cycling-related injuries, hospital admissions, and deaths in the United States. Here, we leverage 3 data sets pertaining to cycling participation, emergency room visits, and cycling-related deaths. We hypothesize that the increase in injuries and deaths is related to an increase in participation among older riders and an increase in injury severity.

Methods

Study population/data sources

The study base is defined geographically as the United States and its territories, because all data are nationally representative of the United States. Data for injuries related to

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bicycles were obtained from the National Electronic Injury Surveillance System (NEISS; U.S. Consumer Product Safety Commission 2000). NEISS is a national surveillance database maintained by the U.S. Consumer Product Safety Commission that collects data on injuries associated with consumer products from approximately 100 emergency departments in the United States. Emergency departments included in the NEISS national probability sample are distributed throughout the United States and its territories. Selection of emergency departments consisted of stratified sampling techniques by 4 size strata and 1 stratum for children's hospitals to guarantee that selected hospitals would be nationally representative (Schroeder and Ault 2001). Each year, ratio adjustment to statistical weights based on the sample design ensures that the reported emergency department visits are representative of the total number of visits nationwide (Schroeder and Ault 2001). Within this nationally representative data, we examined all injuries related to bicycles (NEISS product codes 5040 and 5033) from 1997 to 2013 that resulted in a visit to the emergency department. The coding of an injury related to a product was performed by review of medical records at participating centers (U.S. Consumer Product Safety Commission 2000). Additional characteristics associated with individuals who sustained a bicycle-related injury were collected from NEISS and included gender, age, location of injury, and body part injured.

For death data, we used death records from the Fatality Analysis Reporting System (FARS) administered by the NHTSA (U.S. Department of Transportation, NHTSA 2013). This is a national census database of police-reported traffic crashes that resulted in the death of an occupant or nonoccupant of a vehicle within 30 days. Dedicated analysts in all 50 states collect data from existing state databases, including police accident reports; death certificates; state registration, driver licensing, and highway department data; vital statistics; coroner/medical examiner reports; hospital medical reports; emergency medical service reports; and other state records (U.S. Department of Transportation, NHTSA 2013). Data are checked for consistency and updated regularly, and further details are described elsewhere (U.S. Department of Transportation, NHTSA 2013).

Cycling participation data were derived from the National Sporting Goods Association (NSGA) Sports Participation Survey, which has gathered data regarding sports participation annually since 1985 (National Sporting Goods Association 2018). The survey is externally managed by Survey Sampling International, which actively manages a large panel of consumers balanced by indicators of purchase behavior, household size, household income, region, and market size (National Sporting Goods Association 2018). Consumers in the panel were asked about the number of days spent participating in a given activity. From this information, NSGA measures the annual number of participants in each sport/activity, regardless of activity purpose (e.g., leisure, recreation, commuting, or competition). Results for cycling participation were based on 35,000–53,000 individual responses each year. Demographics of responders (including age, gender, and state) were used to make projections on the total number of individuals who ride bicycles in the United States each year, resulting in a nationally representative data set. Frequency of participation was defined as cycling at least once per year or cycling at least 6 times per year in the NSGA survey. We chose to include only individuals who rode a bicycle at least 6 times a year as participants. Population data were obtained from the U.S. Census to calculate incidence rates (U.S. Census Bureau 2017). For all data sources, we excluded all participants under the age of 18.

Predictor/outcome

NEISS codes were used to classify injuries by body part, location, and gender (Appendix Table 1, see online supplement; U.S. Consumer Product Safety Commission 2000). In order to evaluate the effect of participation on bicycle-related injuries and fatalities, population projections of injuries, hospital admissions, and deaths were compared with cycling participation data. The same was done for fatality data. Given that the incidence of injuries varied by age group (Sanford et al. 2015), we evaluated relationships between participation and injuries/hospital admissions/deaths within age groups divided into 10-year intervals. We began with an exploratory data analysis by plotting the distribution of injuries by age group and stratified this injury versus age group by year, which allowed us to determine whether specific age groups showed a large change in injuries/hospital admissions/deaths over time. We then calculated the incidence of injuries/hospital admissions/deaths per participant (versus the U.S. population).

To evaluate associations of injury characteristics with hospital admissions, we developed a multivariable logistic regression model that included year, age, gender, body part injured (head, torso, extremity, other), location (street vs. nonstreet), and injury diagnosis (contusion, laceration contusion, crushing, foreign body, fracture, hematoma, laceration, dental injury, internal organ injury, puncture, strain or sprain, anoxia, poisoning/fume inhalation, avulsion, other). Injury diagnosis categories with less than 100 injury events were placed in an "other" category to prevent instability of the model.

Statistical analysis

Linear regression was performed to evaluate trends in cycling injuries over time. We included age group as an interaction variable to examine whether trends differed for younger and older groups. We then performed a separate multivariable logistic regression to assess the likelihood of hospital admissions taking NEISS complex survey design into account by utilizing weights and strata assigned to each individual. We adjusted for age (10-year groups), body part injured, gender, injury location and year, and injury mechanism. Linear regression was also used to evaluate the relationship between population projections of injuries and national participation within each age group to gain insight

Table 1. Demographics.

	NEISS observed total (%)	Population projection estimate	Population projection 95% CI
Total injuries	96,202 (100)	3,821,460	2,778,988–4,863,932
Race			
White	46,054 (48)	1,947,768	1,359,046–2,536,490
Black	10,493 (11)	291,764	175,839–407,690
Asian	6,805 (7)	18,127	6,992–29,262
Other	568 (1)	4,236	146,285–442,185
Not listed	32,282 (33)	891,793	515,246–1,268,339
Location of injury			
Street	48,621 (51)	1,915,959	1,107,457–2,724,460
Nonstreet	19,108 (20)	786,089	696,848–875,331
Not recorded	28,291 (29)	1,119,411	986,945–1,251,876
Body part injured			
Head injuries	12,807 (13)	478,998	293,574–664,402
Torso injuries	14,740 (15)	588,174	431,317–745,031
Extremity injuries	47,445 (49)	2,118,065	1,616,053–2,620,076
Other injuries	21,210 (22)	608,630	445,803–771,458

into the effect of exposure on injuries. Multivariable analysis was performed with SAS Version 9.3. All other analysis and graphing was performed using R Version 3.2.1 and the ggplot2 package.

Results

In the NEISS cohort, there were a total of 96,020 injuries related to bicycles over the study period, leading to an estimate of 3,821,460 (95% confidence interval [CI], 2,778,988–4,863,932) cycling-related injuries in the United States between 1997 and 2013 (Table 1). The average age of injured cyclists increased from a mean of 35.9 years in 1997 to 38.5 years in 2013 ($P < .01$). Twenty-five percent of injuries occurred in women, and the ratio of injuries occurring in men versus women did not change over the study period ($P = .2$).

Cycling injuries, hospital admissions, and deaths: The impact of age group

The relationship between injuries/hospital, admissions/deaths, and age group demonstrates the change in the distribution of injuries/hospital and admissions/deaths by age group over the 15-year study period. (Appendix Figure 1, see online supplement) There are noticeable increases in injuries, hospital admissions, and deaths among those over the age of 45 during the study period. Based on examination of the distribution of injuries, there appeared to be a rise in injuries in individuals over 45 years of age. We therefore used age 45 as a cutoff to evaluate the effect of age group (<45 and >45) on injuries over time while correcting for the independent effect of participation (Appendix Table 2, see online supplement). For injuries, neither the age group variable nor the interaction variable between year and age group were significant (i.e., the slope of the regression lines for age <45 and >45 was not different). The participation variable was significant, indicating that changes in overall participation could explain observed changes in injuries. However, for both hospital admissions and deaths, the interaction between age group and year were significant, indicating that the increasing trends in rates of hospital admission and deaths are different for younger and older cyclists. Participation was no longer significant in the models for hospital admissions and deaths. Also notable in the interaction analysis was the higher rate of injuries in cyclists <45 years of age and a higher rate of hospital admission among individuals <45 years of age.

Injuries, hospital admissions, and deaths: Correcting for cycling participation

Participation rates for adults varied from year to year but did not exhibit a clear linear trend over time. Adult injury rates and hospital admissions increased significantly over time ($P < .01$). Cycling participation data were used to calculate the preparticipant incidence of injuries, hospital admissions, and deaths (Table 2). This demonstrated a relationship between injuries and participation varying by age group (Appendix Figure 2, see online supplement). For the younger age groups (<45), there was no association between injuries and ridership. For the age groups 45–54, 55–64, and 55–76, there was a statistically significant association between participation and injuries. The per participant incidence of both injuries and hospital admissions increased in nearly all age groups (Figure 1). On a per participant basis, it appears that the rates of injury and hospital admission are rising.

Multivariable analysis

The odds ratios (ORs) of hospital admissions for multiple variables are shown in Table 3. There was a 26% increase in the odds of hospital admission (OR = 1.26; 95% CI, 1.19–1.32) with each decade above age 18–24. Within injury categories, the odds of hospital admission were notably increased for head injuries (OR = 3.0; 95% CI, 2.4–3.8) and torso injuries (OR = 4.5; 95% CI, 4.0–5.1) compared to the odds for extremity injuries. Gender and location were also significantly associated with hospital admission. It is notable that year of injury did not have an association with odds of hospital admission. Also notable is the finding that among diagnosis codes, a fracture was associated with the highest odds of being admitted when controlling for location of

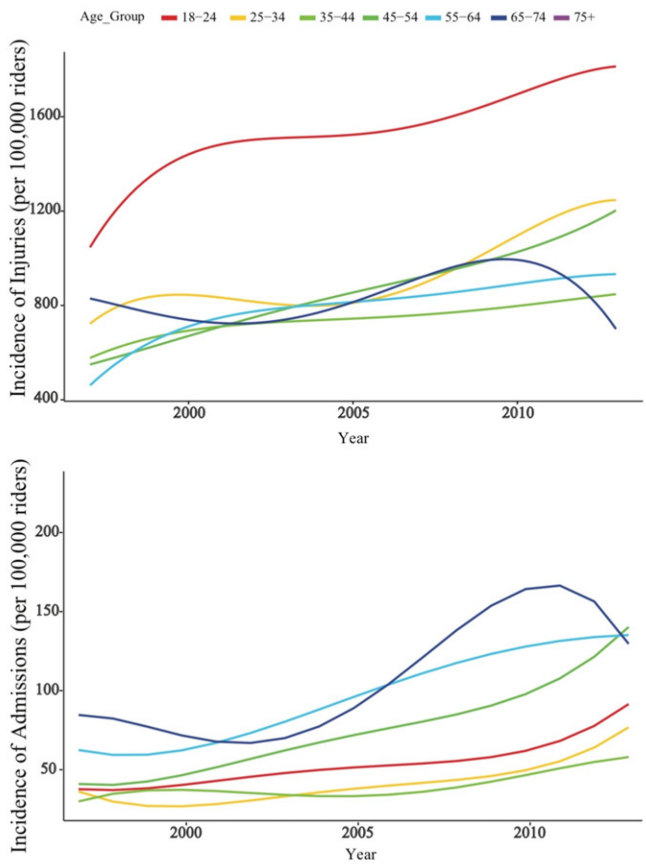

Figure 1. Per cyclist injury trends.

injury (i.e., head, torso, arm) and other variables in the model.

Discussion

We found an increase in the rate of injuries and hospital admissions driven by increases in injuries and hospital admission among individuals >45 years old. Deaths among the >45-year-old population are also rising but with a corresponding decrease in deaths among younger individuals. Our analysis captures unique attributes of the intricacies of the effects of participation and age on the trends in injuries, hospital admissions, and deaths. It appears that the rise in injuries among older adults is primarily due to a mass effect; that is, more individuals over 45 years of age are cycling. Although these cyclists may have a higher risk of injury, the rate of increase in their injuries was the same as that for cyclists under age 45. However, on a per cyclist basis, the rates of injuries are higher for younger cyclists. Thus, although the reasons for trends in injuries among younger versus older age groups are different, when taken in aggregate, the results of this study show increases in the number of injuries per participant.

The trends observed with hospital admissions and deaths were different than those observed for injuries. For hospital admissions and deaths, cyclists over age 45 had an increased rate of admissions and deaths that was significantly greater than that of cyclists aged 45 or younger. Given that hospital admission and deaths are a reflection of injury severity, this study indicates that the older population is more vulnerable to severe injury (Sanford et al. 2015). Overall, the factors most strongly associated with hospital admission in the multivariable model included age 45 and older, head injuries, and torso injuries. One possible explanation for an increase in injuries is a rise in sport cycling, associated with faster speeds, which could be driven by a rise in competitive cycling. Alternatively, there is a reported rise in commuter cyclists who travel on crowded streets during peak traffic hours, which may put them at higher risk (Pucher et al. 2011).

This study contrasts with reports that have found a decrease in injuries related to bicycles over time (Buehler and Pucher 2017; Pucher et al. 1999). There are 2 reasons for this discrepancy. The first is that this study is specific to individuals at least 18 years age; most studies include children in their injury data (Buehler and Pucher 2017; Pucher et al. 1999). In the NEISS database, the rate of overall cycling injuries has been constant despite an increase in cycling-related injuries in adults, suggesting a corresponding decrease in injuries among children (U.S. Consumer Product Safety Commission 2000). The second reason for the discrepancy pertains to the source of data used. Prior studies of cycling-related injuries in the United States have relied on the U.S. Department of Transportation (Buehler and Pucher 2017; Pucher et al. 1999). It has been shown that traffic-related reporting of bicycle-related injuries substantially underestimates injuries compared to evaluation of emergency department records (Lopez et al. 2012). It should be noted that the overall estimate of injuries from the NEISS data released in 2013 was 531,360 (U.S. Consumer Product Safety Commission 2000), whereas the overall estimate of injuries from the U.S. Department of Transportation (2013) was 48,000, again emphasizing the extent of underestimation of injuries when traffic statistics are the sole source of information.

The rising rates of injuries and hospital admissions reported in this study have public health implications. Cities are beginning to invest in infrastructure to make cycling safer, and preliminary evidence shows that bicycle lanes are beneficial (Reynolds et al. 2009). Other studies listed in the Appendix bibliography (see online supplement) also found that cycling lanes and infrastructure are protective. Reversing the nationwide increases in both injuries and hospital admission may involve a coordinated nationwide effort to support more safe-cycling infrastructure, but future research is needed on the topic. Moreover, infrastructure change also may require public policy support and funding. A study in Australia created a prediction model that suggested that a universal policy approach to bicycle-friendly infrastructure involving physical segregation lanes may be necessary to reduce all-cause mortality, reverse physical inactivity, and make the project economically feasible (Macmillan et al. 2014). This effort to make cycling safer will be particularly important as the population of cyclists shifts to an older demographic that is more susceptible to

Table 2. Proportion of injuries, hospital admissions, and deaths due to cycling.

Year	Injury: Participant crude incidence (per 100,000 cyclists)	Hospital admission: Participant crude incidence (per 100,000 cyclists)	Death: Participant crude incidence (per 100,000 cyclists)a
1997	701	41	2
1998	753	38	2
1999	795	44	2
2000	811	40	2
2001	951	45	2
2002	798	43	2
2003	902	52	2
2004	840	50	2
2005	752	52	2
2006	980	62	3
2007	946	60	2
2008	1,062	75	3
2009	1,005	77	2
2010	1,044	84	2
2011	1,088	85	2
2012	1,036	91	2
2013	1,164	109	3
P value for trend	<.01	<.01	.13

[a]Only deaths involving a motor vehicle are included.

Table 3. Multivariable model for hospital admissions.

	Multivariable OR (95% CI)	*P* value
Age (10-year ranges, reference age group 18–24)	1.26 (1.19–1.32)	<.01
Body part		
Extremity	Ref (1)	
Head	2.88 (2.30–3.60)	<.01
Torso	4.52 (4.00–5.10)	<.01
Other	2.79 (2.30–3.30)	<.01
Gender		
Female	Ref (1)	
Male	1.33 (1.14–1.55)	<.01
Location		
Nonstreet	Ref (1)	
Street	1.71 (1.32–2.20)	<.01
Not listed	0.92 (0.71–1.19)	.52
Year	1.01 (0.99–1.03)	.36
Diagnosis		
Fracture (57)	Ref (1)	
Concussion (52)	0.52 (0.37–0.80)	<.01
Contusion/abrasion (53)	0.05 (0.03–0.07)	<.01
Foreign body (56)	0.05 (0.02–0.12)	<.01
Hematoma (58)	0.33 (0.21–0.53)	<.01
Laceration (59)	0.20 (0.07–0.32)	<.01
Dental injury (60)	0.11 (0.05–0.23)	<.01
Internal organ injury (62)	0.75 (0.59–0.95)	.02
Puncture (63)	0.25 (0.14–0.44)	<.01
Strain or sprain (64)	0.13 (0.01–0.23)	<.01
Poisoning/fume inhalation (68)	0.27 (0.16–0.46)	<.01
Other/not stated (71)	0.38 (0.21–0.75)	<.01
Avulsion (72)	0.39 (0.21–0.75)	<.01
Other	0.86 (0.55–1.37)	.55

severe injury. One study in northern Sweden using a catchment hospital as a primary study base examined bicycle injuries among older adults (age ≥65) and that found half of the injured had moderate to severe injuries such as fractures or dislocations (Scheiman et al. 2010). In some countries, older adults represent half of cycling fatalities, and medical treatment for survivors can be costly (Scheiman et al. 2010). However, incidence rates of any kind of injury in younger populations—regardless of severity—tend to be higher, as shown in the present study. Making cycling safer is also a necessary part of increasing active transport—more bicycle lanes and other commuter-friendly infrastructure increase the utilization of active transport, thus combating the effects of a sedentary society (Dill and Carr 2003).

There are limitations in this study. We do not have data regarding the speed of the cyclists, the distance or time traveled per year, the ratio of cyclists injured by motor vehicles versus cyclist-only injuries, or the use of personal protective equipment (including helmets). Without information on kilometers traveled, it is possible that an increase or decrease in this variable over the study period could explain variations in cycling injuries, hospital admissions, and deaths. Although there is an indication that the number of road cycling trips increased over the study period (Pucher et al. 2011), future studies should investigate distance traveled and injury trends. In addition, our participation data are based on self-reported cycling more than 6 times per year rather than distance traveled. FARS bicycle death data are limited to motor vehicle–related deaths on publicly accessible roads, and deaths not involving motor vehicles such as those due to mountain biking are not recorded. However, mountain biking deaths are rare, with one study in the greater Vancouver area reporting only one fatality from mountain biking from 1992 to 2002 (Kim et al. 2006). It is important to note, though, that our fatality data most accurately reflect motor vehicle–related fatalities, and fatality results should be interpreted accordingly. Despite these limitations, we believe this study to be the most comprehensive evaluation of cycling injuries in adults in the United States to date.

On a per cyclist basis, the rate of injury appears to be increasing the fastest for younger cyclists compared to older cyclists. Thus, it appears that the rate of rise in younger cyclists appears to be, in part, due to an increase in the danger of cycling. However, when hospital admissions are examined, the opposite is true: Older cyclists appear to have the greatest change in the rates of hospital admissions over time. The death data are not remarkable, likely due to the low numbers of deaths compared to the number of participants.

Riding a bicycle is a form of physical activity that is associated with improvement in overall health despite the risks associated with it, particularly when used as a form of active transport. One of the greatest barriers to increasing participation is the perception that cycling is dangerous (Macmillan et al. 2014). We show that injuries and hospital admissions are increasing on a per participant basis, though it is necessary to examine kilometers traveled to determine whether injury rates per exposure are on the rise. The reasons for this rise in per participant injuries are intricate and appear to be age group specific. Further investment in infrastructure is an important avenue to prevent a further increase in bicycle-related injuries in the United States and to improve the rate of participation.

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