Trends in school-age pedestrian and pedalcyclist crashes in the USA: 26 states, 2000–2014

Katherine C Wheeler-Martin ,[1,2] Allison E Curry,[3,4] Kristina B Metzger,[3] Charles J DiMaggio [1,2]

[1]Surgery, NYU Langone Medical Center, New York City, New York, USA
[2]Population Health, NYU Langone Medical Center, New York City, New York, USA
[3]Center for Injury Research and Prevention, Children's Hospital of Philadelphia, Philadelphia, Pennsylvania, USA
[4]Pediatrics, University of Pennsylvania Perelman School of Medicine, Philadelphia, Pennsylvania, USA

Correspondence to
Katherine C Wheeler-Martin, Surgery, NYU Langone Medical Center, New York, NY 10016, USA; katherine.wheeler-martin@nyumc.org

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ABSTRACT

Background Despite substantial progress, motor vehicle crashes remain a leading killer of US children. Previously, we documented significant positive impacts of Safe Routes to School interventions on school-age pedestrian and pedalcyclist crashes.

Objective To expand our analysis of US trends in motor vehicle crashes involving school-age pedestrians and pedalcyclists, exploring heterogeneity by age and geography.

Methods We obtained recent police-reported crash data from 26 states, calculating population rates of pedestrian and pedalcyclist crashes, crash fatality rates and pedestrian commuter-adjusted crash rates ('pedestrian danger index') for school-age children as compared with other age groups. We estimated national and statewide trends by age, injury status, day and travel hour using hierarchical linear modeling.

Results School-age children accounted for nearly one in three pedestrians and one in two pedalcyclists struck in motor vehicle crashes from 2000 to 2014. Yet, the rates of these crashes declined 40% and 53%, respectively, over that time, on average, even as adult rates rose. Average crash rates varied geographically from 24.4 to 100.8 pedestrians and 15.6 to 56.7 pedalcyclists struck per 100 000 youth. Crash rates and fatality rates were inversely correlated.

Conclusions Despite recent increases in adult pedestrian crashes, school-age and younger pedestrians experienced ongoing declines in motor vehicle crashes through 2014 across the USA. There was no evidence of displacement in crash severity; declines were observed in all outcomes. The growing body of state crash data resources can present analytic challenges but also provides unique insights into national and local pedestrian crash trends for all crash outcomes.

BACKGROUND

While motor vehicle crash fatality rates have substantially declined over the past 30 years in the USA, there has been a recent increase in pedestrian fatalities in the past 5 years.[1] In 2016, motor vehicle crashes still remained the leading cause of death in children and young adults aged 5–24 years,[2] and one in four children killed in traffic crashes in 2016 was a pedestrian or pedalcyclist.[3] Youth pedestrian and bicyclist crash trends are of particular concern given the growing efforts to promote active transportation through walking and bicycling over the past decade, including the federal Safe Routes to School (SRTS) programme,[4] intended in part to help to combat rising rates of physical inactivity and obesity in the USA.[5 6]

Fatal crashes are reportable by law in all 50 states and collected in a standard public data repository, the Fatality Analysis Reporting System.[7] Most studies and national reports on pedestrian crashes are derived from these fatality data. Conversely, non-fatal crashes are not subject to uniform surveillance. Yet, non-fatal pedestrian injuries are far from trivial events, especially in children. Pedestrian injuries may account for 30%–60% of all injury hospital admissions in children[8] and have been cited as the most common cause of traumatic brain injury for 5–9 years olds.[9] In addition to physical consequences, one in six injured children develop longer-term psychological sequelae.[10–12] Hospital and emergency department data and trauma registries, therefore, also provide an important source of information on pedestrian injuries.[13] However, such data generally contain limited information about crash circumstances, roadway, vehicle and driver characteristics.

The National Highway Traffic Safety Administration (NHTSA) maintains a census of police-reported motor vehicle crashes from the 34 states currently participating in the State Data System (SDS).[14] A growing number of states also make their police-reported crash data publicly available through individual state websites. National-scale analyses of these data present significant challenges due to variations in state-reporting protocols, disparate coding practices and the need for expanded computing power. Nonetheless, these data allow for a comprehensive analytic scope inclusive of the universe of reported crashes. Specifically, they allow for estimation of crash case fatality rates and detailed geographic analyses, as compared with the national General Estimating System, now the Crash Report Sampling System (CRSS),[15] for example. The CRSS contains crash data systematically sampled from 60 US sites to produce national crash estimates, but is not designed for state-level or sub-state analyses.

Building on our previous work,[16] our overall objective was to update and expand descriptive analyses of trends in US youth pedestrian crashes, including non-fatal crashes. Specifically, we aimed to compare crash and fatality rates for school-age pedestrians and pedalcyclists with other age groups, and to explore geographic heterogeneity. To this end, we combined and standardised state-level crash data from 22 SDS and 4 non-SDS state crash data repositories for a 15-year period, 2000–2014, to examine recent multistate trends in school-age pedestrian and pedalcyclist crashes overall and by state. We also sought to describe whether or not school-age pedestrian and pedalcyclist crash rates varied over time with respect to injury severity, day of week and time of day, specifically morning and afternoon school travel hours, which have been the focus of interventions to reduce school travel-related pedestrian injuries. To the best of our knowledge, this effort represents the most up to date, comprehensive descriptive epidemiological analysis of youth pedestrian and cyclist crashes in the USA. These results establish a baseline against which to measure interventions, provide injury control practitioners with relevant local data and set the stage for future research.

METHODS

Data sources

Our research protocol was certified as exempt from review by the New York University School of Medicine Institutional Review Board because it did not involve interaction with human subjects or identifiable protected health information. NHTSA approved our request to petition SDS-participating states to purchase and use their SDS crash data in our study. A total of 22 states responded and granted access to available years of partially de-identified record level crash data supplied to SDS (no names, dates of birth or addresses). Additional state crash data were obtained for California 2011–2014 to supplement their SDS data,[17] as well as four additional non-SDS states: Connecticut 2003–2014,[18] Texas 2008–2014,[19] Kentucky 2004–2014[20] and New Jersey 2004–2014 (Children's Hospital of Philadelphia), for a total of 26 states. Annual population estimates for each state and age group were obtained from the US Census Bureau's Population Estimates data programme.[21] Self-reported commuting data were obtained from the US Census Bureau's American Community Survey.[22]

INCLUSION CRITERIA AND DATA PREPARATION

All 26 states in this study mandate police reporting of crashes involving fatalities or injuries. Non-injury reporting criteria vary by state, based on vehicular and other property damage related to the crash (table 1, footnote). The study period consisted of the most recent 15 years of SDS data available at the time of request in 2017–2018, which were the years 2000–2014 as available by state (table 1). Annual data sets missing pedestrian or bicyclist age were excluded (Minnesota after 2003 and Washington before2012) from the analysis. Time of crash and day of week were available for all data sets included in analyses. We defined school travel hours as 07:00–09:00 and 14:00–16:00, encompassing most typical school travel times in the USA.[16] Pedestrian injury status was based on standard KABCO scoring ranging from uninjured to killed.[23] We standardised the terminology, which varied slightly by state, as 'no injury', 'possible injury', 'non-incapacitating injury', 'incapacitating injury', 'fatal injury' and 'unknown'. Incapacitating injuries are generally defined as those rendering the victim unable to leave the scene unassisted, including broken bones, severe lacerations or unconsciousness; non-incapacitating injuries may include bruises and minor lacerations.

MEASURES AND STATISTICAL ANALYSES

Data were imported into R V.3.5.1 as a column-oriented database using MonetDB. Crash rates were calculated as the number of pedestrians or bicyclists struck per 100 000 annual census population estimates, stratified by age as: 1–4 (pedestrians only), 5–19, 20–24, 25–64 and 65+ years olds. The numerator included pedestrians and bicyclists up to age 120 years and excluded those with values of 0 and 99 for age, which were used to denote 'unknown' in some state crash data sets. As we were unable to exclude ages <1 and 99 years from the population denominator data, population-based rates are approximate.

Crash case fatality rates were calculated per 100 pedestrian or pedalcyclist crashes. The *pedestrian danger index* was adapted from Atherton *et al*,[24] wherein we multiplied each state's population denominator by the state's proportion of commuters who travel by foot or use public transportation as their primary form of travel to work using American Community Survey data. Thus, the pedestrian danger index approximates the rate of crashes per 100 000 persons who use public transit or walk to work, as a surrogate of the average daily pedestrian density. While this assumes youth walking patterns mimic adult commuting trends, in our recent work using New York City crash data, we demonstrated that the proportion of adults walking and using public transportation was significantly associated with youth pedestrian crash rates at the neighbourhood level (Morris M, Wheeler-Martin K, Mooney S *et al*, in press).

Annual age-specific trends in rates of pedestrian and bicyclist crashes were estimated using hierarchical linear modeling (HLM) for the predictor variable, year, allowing for varying slope and intercept by state. Because the slopes for some age groups appeared to change over time in preliminary analyses, we conducted piecewise hierarchical regression in three 5-year periods to improve the fit of the modelled results and characterise changes in age-specific rates. The rate of change for the school-age subset, meanwhile, appeared to be constant over time. Therefore, subsequent regression models for the school-age subset, which explored differences in rates over time by injury type, day of week and time of day, used the singular 15-year time period. Coefficients, standard errors and p values were obtained using the lmerTest package with Satterwaithe estimates for p values. The general format of the varying slope, varying intercept HLM equation with one predictor, is: $y_i=\alpha_{j[i]}+\beta_{j[i]}x_i+\epsilon_i$, where i is the smallest unit of observation, j is a grouping level, y is the outcome, x is a predictor variable, β is the slope coefficient for the predictor and ϵ is the error term.[25] Thus, in the varying slope, varying intercept HLM, both α and β vary by group j.

In R, our model took the form: lmer(CrashRate~(1+Year|State)+Year), which allowed for the estimation of (1) a global intercept, (2) random-effect intercepts for each state, (3) a global estimate for the effect of year, (4) estimates of the effect of year within each state and (5) the correlation between intercepts and slopes.

RESULTS

Summary statistics: overall and by state

Our analytic data set included crash data for 1 180 135 pedestrians and 663 109 bicyclists struck in motor vehicle crashes in 26 states from 2000 to 2014 (years available inclusive of pedestrian age varied by state, table 1). On average across the 26 states, school-age children aged 5–19 years accounted for 299 857 or 29.0% (95% CI 27.2% to 30.2%) of pedestrians struck and 232 791 or 44.3% (95% CI 40.4% to 48.1%) of bicyclists struck, whereas this age group accounted for 20% of the US 2010 population among states included in our analyses.

The average state annual rate of school-age pedestrian crashes was 42.9 per 100 000 population (95% CI 42.0 to 43.8) year period. This varied fourfold across the 25 states, ranging from approximately 25 per 100 000 in Arkansas to 100 per 100 000 in New York (table 1, figure 1A). Similarly, the average annual rate

Table 1 Summary of school-age pedestrian and bicyclist crashes (total, injuries and deaths), percentages of all-age totals, rates of individuals struck per 100 000 population aged 5–19 years and crash fatality rates (proportion killed), 26 states, 2000–2014

		School-age pedestrians in motor vehicle crashes								School-age pedalcyclists in motor vehicle crashes							
State	Years available	Total	Pct. of all-age total	Injuries	Pct. of all-age injured	Deaths	Pct. of all-age deaths	Avg. ped. crash rate per 100 000 pop'n	Avg. crash fatal rate (%)	Total	Pct. of all-age total	Injuries	Pct. of all-age injured	Deaths	Pct. of all-age deaths	Avg. pedal. crash rate per 100 000 pop'n	Avg. crash fatal rate (%)
Arkansas*	2000–2013	1993	31.7	1786	33.8	62	10.9	24.4	3.1	1275	53.6	1088	54.8	9	20.9	15.6	0.7
California†	2000–2014	64 046	29.1	60 043	29.9	953	9.4	54.4	1.5	66 891	33.8	59 063	33.2	294	15.4	56.9	0.4
Connecticut‡	2000–2014	4761	27.9	4506	28.7	49	8.7	44.3	1.0	4658	47.4	4120	47.8	24	38.7	43.3	0.5
Florida§	2000–2014	27 753	22.2	25 501	23.5	597	8.1	55.6	2.2	20 100	25.6	18 202	26.3	177	11.2	40.2	0.9
Georgia†	2000–2010	7473	29.5	6369	31.1	210	12.8	35.0	2.8	3742	41.0	2922	41.9	50	27.0	17.6	1.3
Illinois¶	2000–2014	25 526	30.2	24 833	30.8	242	10.7	63.6	0.9	20 096	40.9	19 231	41.2	81	22.8	50.1	0.4
Iowa**	2001–2005	783	39.3	758	40.6	13	16.0	25.0	1.7	1332	56.6	1299	57.1	12	28.6	42.5	0.9
Kansas††	2000–2014	2504	34.4	2381	35.6	38	11.7	27.7	1.5	2463	50.7	2321	51.0	15	23.4	27.2	0.6
Kentucky†	2004–2014	3686	24.2	3094	25.0	70	10.9	39.2	1.9	2252	42.6	1648	42.9	15	25.9	24.0	0.7
Maryland¶	2000–2014	12 251	28.3	10 506	29.0	166	10.9	70.7	1.4	5673	47.5	4523	47.1	28	26.2	32.7	0.5
Michigan‡‡	2000–2014	11 880	32.0	10 327	33.2	263	12.0	37.4	2.2	13 164	46.4	10 849	46.3	98	26.8	41.3	0.7
Minnesota‡	2000–2002	1082	31.0	1059	31.8	20	14.7	32.5	1.8	1663	57.1	1589	57.8	9	32.1	50.0	0.5
Missouri†	2000–2014	6908	30.1	6272	31.2	154	13.3	38.0	2.2	5355	52.4	4457	52.2	36	39.6	29.5	0.7
Montana‡	2000–2008	488	32.1	415	33.3	12	11.3	27.6	2.5	746	46.8	639	46.3	11	42.3	42.2	1.5
Nebraska‡‡	2000–2013	2459	31.5	2414	32.0	21	12.0	46.0	0.9	2389	53.0	2319	53.1	8	30.8	44.6	0.3
New Jersey†	2004–2014	13 164	22.2	10 887	23.1	111	7.8	68.3	0.8	8530	38.0	6678	38.1	22	16.5	44.2	0.3
New Mexico†	2000–2008	1093	26.0	965	28.6	38	7.5	28.4	3.5	1138	37.5	986	38.1	7	15.9	29.6	0.6
New York‡	2000–2013§§	50 140	24.8	48 033	25.1	365	9.2	100.8	0.7	26 910	36.6	25 840	36.4	129	24.5	54.0	0.5
North Carolina‡	2000–2006	4298	23.8	3756	24.9	139	11.6	35.5	3.2	2937	40.4	2562	41.6	48	26.1	24.3	1.6
Ohio	2000–2014	14 774	35.1	12 859	35.8	227	15.8	41.3	1.5	17 617	57.3	14 244	57.3	64	26.9	49.1	0.4
Pennsylvania¶	2000–2012§§	20 125	34.8	19 679	35.7	222	11.7	67.3	1.1	9638	52.4	9392	52.8	71	38.2	32.2	0.7
South Carolina‡	2001–2014	3102	22.9	2840	24.6	137	9.8	24.6	4.4	2200	30.2	2003	30.4	36	15.9	17.5	1.6
Texas††	2008–2014	11 325	24.3	10 160	25.4	295	9.4	28.3	2.6	6649	35.9	5699	35.8	62	18.1	16.6	0.9
Virginia‡	2000–2013§§	6484	26.5	6360	27.2	123	11.1	32.5	1.9	3831	35.6	3663	35.9	36	22.2	17.9	0.9
Washington¶¶	2011–2013	1496	24.9	1329	25.3	20	10.2	37.7	1.3	1112	26.0	979	26.0	7	19.4	28.0	0.6
Wyoming‡	2000–2007	263	34.4	256	35.7	7	15.2	30.1	2.7	430	64.6	416	65.4	2	25.0	49.0	0.5
Total		299 857	29.0	277 388	30.0	4554	11.3	42.9	2.0	232 791	44.3	206 732	44.5	1351	25.4	35.4	0.7

Reporting criteria other than injury or death.
*US$500–US$2000 damage (threshold increased over study period).
†US$500 damage.
‡US$1000 damage.
§Under the influence, hit and run or vehicle disabled.
¶Vehicle disabled.
**US$500–US$1500 damage (threshold increased over study period).
††US$500–US$1000 damage (threshold increased over study period).
‡‡US$400–US$1000 damage (threshold increased over study period).
§§Timespan excludes 2001 (New York), 2002 (Pennsylvania) and 2009 (Virginia).
¶¶US$700 damage.
Avg., average; Pct., percentage; ped., pedestrian; pedal., pedalcyclist; pop'n, population.

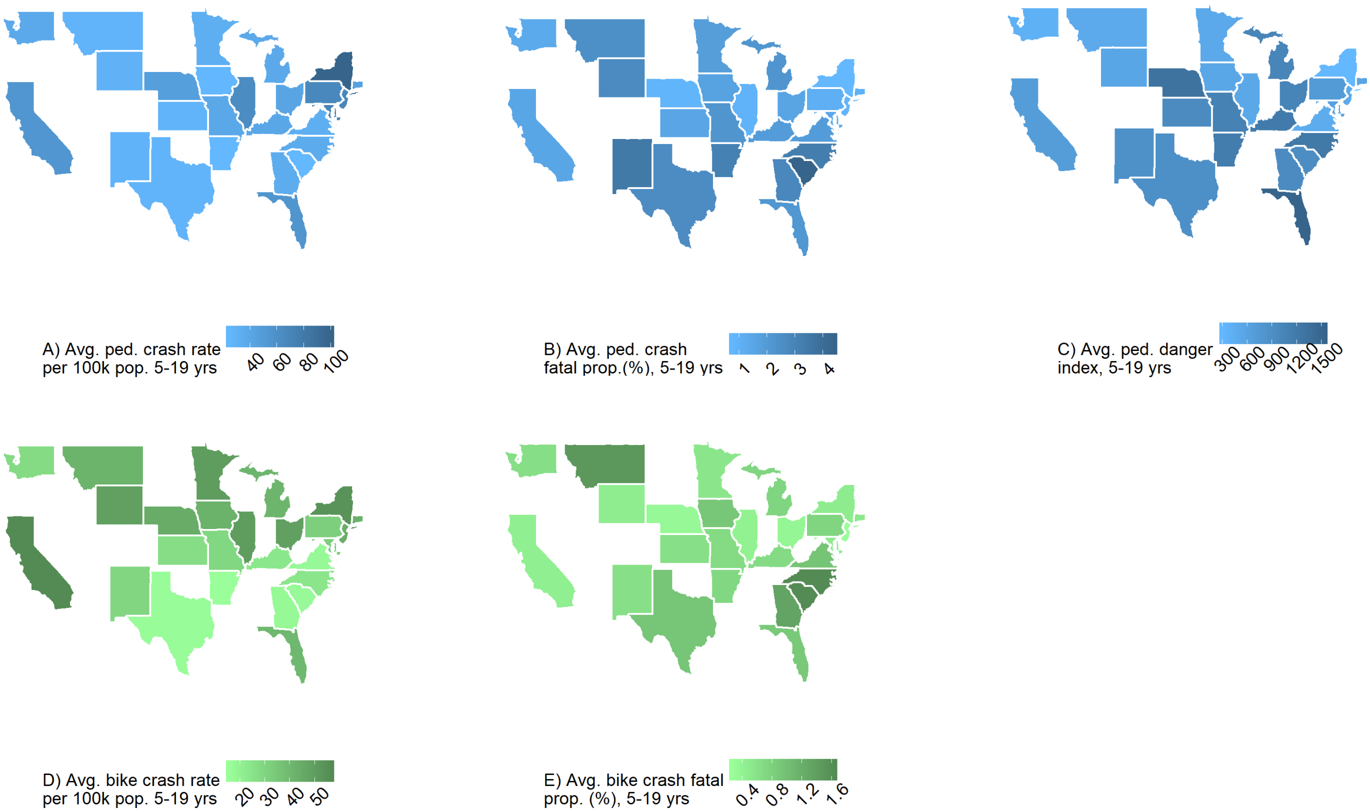

Figure 1 Average annual school-age pedestrian crash rate per 100 000 population aged 5–19 years (A), average annual school-age pedestrian crash fatality rate (per cent killed) (B), average annual school-age pedestrian danger index (C), average annual school-age bicyclist crash rate per 100 000 population aged 5–19 years (D) and average annual school-age bicyclist crash fatal proportion (E) for the years 2000–2014 as available by state. 100k, 100 000; Avg., average; ped., pedestrian; pop., population; prop., proportion; yrs, years.

of school-age bicyclist crashes was 35.4 per 100 000 school-age children (95% CI 32.3 to 38.4), which varied nearly threefold geographically, from less than 20 per 100 000 in Arkansas to over 50 per 100 000 in California (table 1, figure 1D). Geographic patterns in crash burdens differed between population rates (figure 1A) and both crash fatality rates (figure 1B) and pedestrian commuter-adjusted crash rates, also known as the pedestrian danger index (figure 1C).

A total of 277 388 school-age pedestrians and 206 732 school-age bicyclists sustained suspected or discernable injuries as reported in police crash reports (92% and 88% of reported school-age crashes, respectively), with 4554 fatal pedestrian injuries and 1351 fatal bicyclist injuries (1.5% and 0.5% of all school-age crashes, respectively). On average, 35.7% (95% CI 32.3% to 39.1%) of school-age pedestrians sustained possible injuries, 42.7% (95% CI 39.3% to 46.2%) sustained non-incapacitating injuries, 16.5% (95% CI 13.1% to 19.9%) sustained incapacitating non-fatal injuries and 2.1% (95% CI 0.1% to 5.5%) were killed. A similar pattern was observed among school-age bicyclist crashes.

Geographically, areas having the highest burden in school-age pedestrian and bicyclist crash fatality rates (deaths per 100 crashes) differed from areas having the highest crash rates (figure 1C,E). There was a significant inverse relationship between school-age pedestrian crash rates and the proportion of pedestrian crashes that resulted in death (Spearman's rho=−0.734, $p<0.001$) (figure 2A). The same was true for youth bicyclist crash rates and fatality rates (Spearman's rho=−0.714, $p<0.001$). The pedestrian danger index, meanwhile, was positively correlated with crash fatality rates (Spearman's rho=0.407, $p<0.001$) (figure 2B).

TRENDS OVER TIME BY AGE, INJURY STATUS, DAY AND TRAVEL HOUR

School-age children experienced an overall 40% decline in pedestrian crashes and 53% decline in bicyclist crashes between 2000 and 2014 based on piecewise hierarchical linear regression (figure 3A,B). Declines were also seen in each individual state, with slope coefficients for year ranging from −0.7 to −3.9 for school-age pedestrians, and −0.9 to −3.7 for school-age bicyclists. School-age pedestrian and bicyclist crashes also decreased significantly in each of the three time periods, 2000–2004, 2005–2009 and 2010–2014 (table 2). Very young children, similarly, experienced sustained declines in pedestrian crashes. Adults, on the other hand, experienced increases in pedestrian and bicyclist crashes in the latter part of the time period.

There were significant declines in all categories of injuries for school-age pedestrians and bicyclists over the time period 2000–2014 (table 3). Parallel declines were observed on weekdays and weekends (table 3). At the beginning of the 15-year period, rates of afternoon school-age pedestrian crashes were approximately 50% higher than morning travel hour crash rates. By the end of the time period, afternoon crash rates declined to the same level as morning travel hour pedestrian crash rates; both trends were statistically significant. The same patterns were observed for school-age bicyclists.

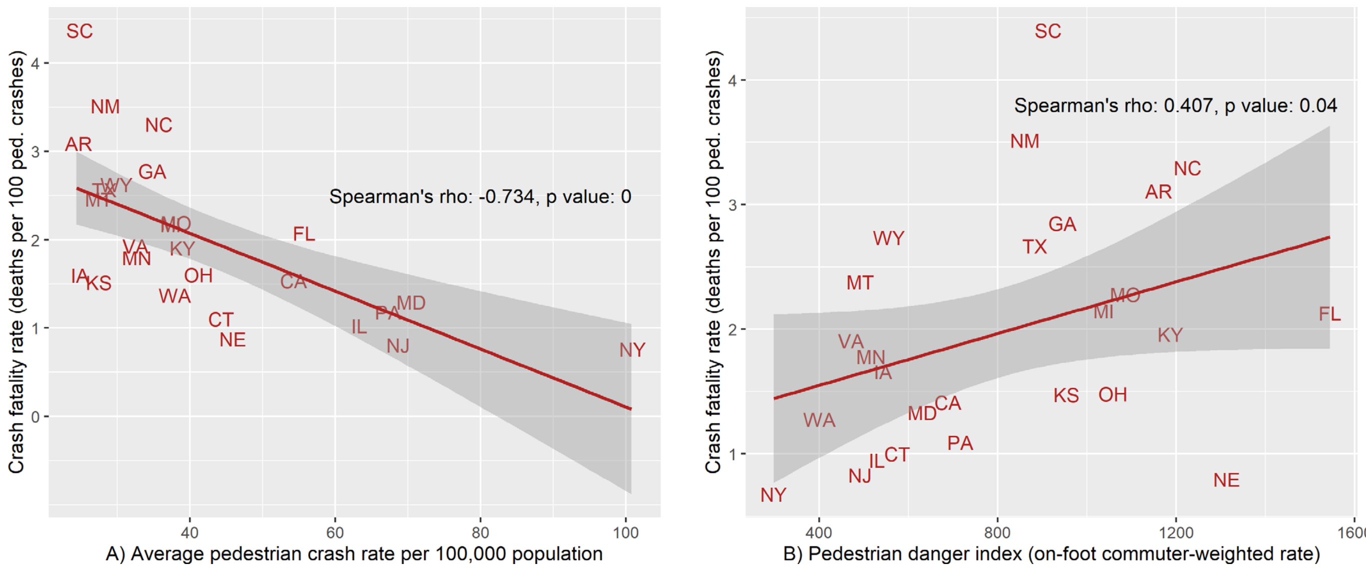

Figure 2 Correlation of (A) school-age pedestrian crash rates and crash fatality rates (per cent killed) and (B) school-age pedestrian danger index (pedestrian commuter-weighted rate) and crash fatality rates. AR, Arkansas; CA, California; CT, Connecticut; FL, Florida; GA, Georgia; IA, Iowa; IL, Illinois; KS, Kansas; KY, Kentucky; MD, Maryland; MI, Michigan; MN, Minnesota; MO, Missouri; MT, Montana; NC, North Carolina; NE, Nebraska; NJ, New Jersey; NM, New Mexico; NY, New York; OH, Ohio; PA, Pennsylvania; SC, South Carolina; TX, Texas; VA, Virginia; WA, Washington; WY, Wyoming; ped., pedestrian.

DISCUSSION

We analysed trends in police-reported motor vehicle crashes with school-age pedestrians and bicyclists for the years 2000–2014, comparing trends over time across states and with respect to other age groups. Our results indicate that school-age children continue to be at increased risk. While only one in five Americans is school-aged, this group accounts for nearly one in three pedestrian crashes and half of all bicyclist crashes from 2000 to 2014.

However, we observed substantial declines in all injury outcomes for school-age children from 2000 to 2014, similar to published declines in youth fatalities between 2007 and 2016.[3] This finding stands in contrast to overall trends in pedestrian and bicyclist fatalities, which have been recently increasing in the USA.[1] Towards the end of the 15-year period, we observed a reversal in the long-standing exceedances in youth crash rates; whereas adult pedestrian and bicyclist crashes began to rise in the second half of the time period, youth pedestrian and bicyclist crashes continued to decline.

Geographic variability in crash rates and fatality rates is undoubtedly related to variation in the distribution of numerous pedestrian crash risk factors identified in previous studies, including population density, traffic density, traffic speed, socioeconomic factors and built environment design.[26] In this study, states having the most pedestrian or bicyclist crashes per capita tended to have large metropolitan areas and more frequent use of public transportation, walking and bicycling to work. When weighting pedestrian crash rates by on-foot commuting rates

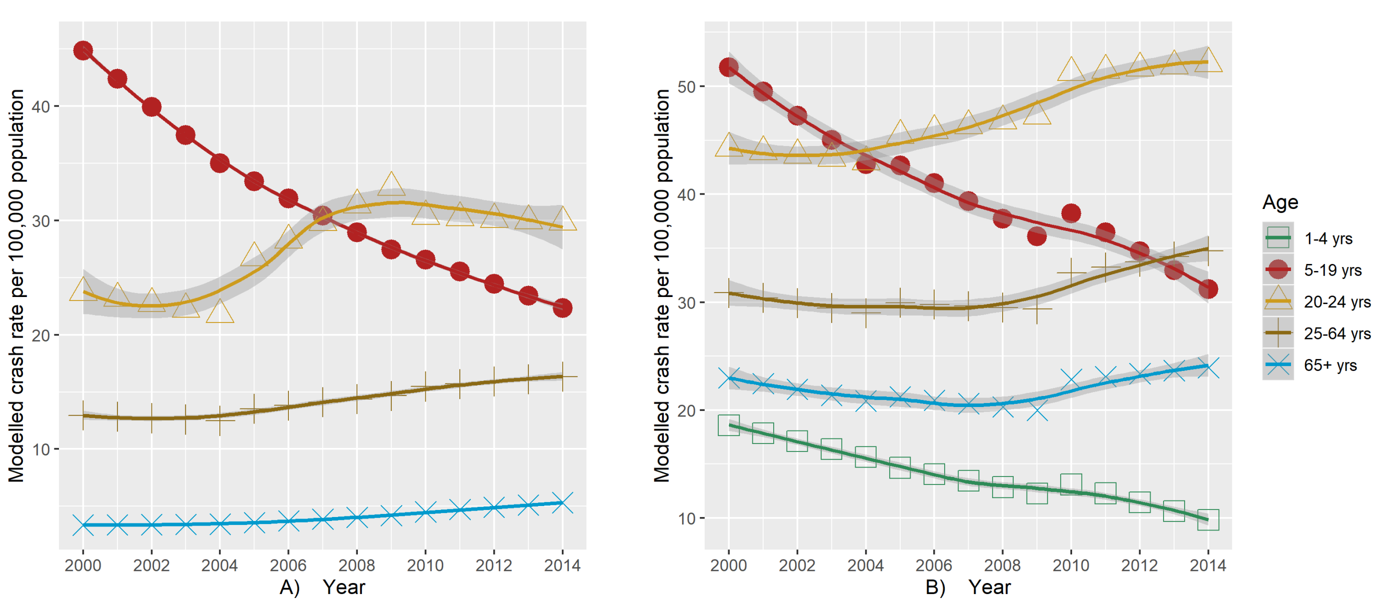

Figure 3 Fitted point estimates from piecewise hierarchical linear regression across three time periods, with loess smoothing lines, for rates of pedalcyclist (A) and pedestrian (B) crashes per 100 000 population by age group, 26 states: 2000–2004, 2005–2009 and 2010–2014. yrs, years.

Table 2 Piecewise hierarchical linear regression coefficients for three time periods, with standard errors, and p values for effect of time (year) on pedestrian and bicyclist crash rates by age group, 26 states, 2000–2014

		Pedestrians in motor vehicle crashes				Pedalcyclists in motor vehicle crashes			
Years	**Age group (years)**	**Intercept**	**Beta (year)**	**SE**	**P value**	**Intercept**	**Beta (year)**	**SE**	**P value**
2000–2004	1–4	18.6	−0.7	0.3	0.011				
	5–19	51.7	−2.2	0.4	<0.001	44.9	−2.5	0.6	<0.001
	20–24	44.3	−0.3	0.4	0.436	23.7	−0.5	0.4	0.235
	25–64	30.9	−0.5	0.2	0.056	12.9	−0.1	0.1	0.44
	65+	23.0	−0.5	0.2	0.021	3.4	0.0	0.1	0.728
2005–2009	1–4	14.7	−0.6	0.2	0.002				
	5–19	42.7	−1.6	0.3	<0.001	33.4	−1.5	0.2	<0.001
	20–24	45.4	0.5	0.3	0.178	26.7	1.5	0.5	0.012
	25–64	29.9	−0.1	0.1	0.3	13.5	0.3	0.1	0.013
	65+	21.2	−0.3	0.1	0.041	3.6	0.2	0.1	0.146
2010–2014	1–4	13.0	−0.8	0.2	<0.001				
	5–19	38.2	−1.8	0.4	<0.001	26.6	−1.1	0.3	<0.001
	20–24	51.2	0.2	0.4	0.612	30.4	−0.1	0.4	0.747
	25–64	32.7	0.5	0.2	0.014	15.5	0.2	0.2	0.174
	65+	22.9	0.3	0.2	0.194	4.5	0.2	0.1	0.012

(aka 'pedestrian danger index'), a different pattern emerged. For example, New York State had the highest rate of youth pedestrian crashes per 100 000 population but the lowest pedestrian danger index, considering it has the largest population of commuters who take public transportation and/or walk to work.

Likewise, we observed an inverse relationship between pedestrian crash rates (crashes per 100 000 population) and pedestrian crash fatality rates (deaths per 100 pedestrian crashes) by state. This is not unexpected. A recent analysis of all-age pedestrian fatality in metropolitan areas also found lower fatality risk where pedestrian and bicyclist mode shares were higher,[27] reflecting on the potential role of 'safety in numbers'.[28] That is, despite the higher probability of pedestrian crashes in urban areas on a population basis, crash severity is lower than in rural areas, which may be due to factors such as traffic speed, availability of sidewalks and other safety measures, and travel times to hospitals.[29 30] Moreover, when walking exposure patterns are taken into account, crash rates based on miles walked are not elevated in urban areas compared with rural areas.[31] In previous research, we and others have found simultaneous decreases in youth pedestrian injuries associated with the implementation of SRTS and efforts aimed at increasing pedestrian and bicyclist travel.[16 32–35]

In this study, we did not observe a shift from fatal outcomes to more non-fatal outcomes, indicating that decreases in mortality are not fully explained by improved trauma care.[36] More change was observed in weekday afternoon travel hours rates compared with weekday morning travel hours. This may partially reflect 'regression to the mean' as afternoon travel hour crash rates were more than 50% higher than morning travel hour crash rates in the early 2000s. Other factors may include higher variability in student activities and changing patterns in activity during afternoon travel hours, nor can we rule out impacts of pedestrian injury prevention programme, such as SRTS.

LIMITATIONS

State crash data vary in availability by state and year; however, we observed that included states were similar to non-included states with respect to average population density (187.5 vs 202.5 persons per square mile in 2010), workers commuting by a private vehicle (87.5% vs 87.9% in 2010–2014) and average

Table 3 Hierarchical linear regression coefficients, SEs and Satterwaithe p values for effect of time (year) on school-age pedestrian and bicyclist crash rates stratified by injury type, weekday and commute hour, 26 states, 2000–2014

	Pedestrians in motor vehicle crashes				Pedalcyclists in motor vehicle crashes			
Stratum	**Intercept**	**Beta (year)**	**SE**	**P value**	**Intercept**	**Beta (year)**	**SE**	**P value**
Injury type								
Possible	15.4	−0.6	0.1	<0.001	11.3	−0.5	0.1	<0.001
Non-incapacitating	16.8	−0.7	0.1	<0.001	15.7	−0.9	0.1	<0.001
Incapacitating	6.2	−0.4	<0.1	<0.001	3.2	−0.2	<0.1	<0.001
Death	0.8	−0.1	<0.1	<0.001	0.3	−0.1	<0.1	<0.001
Day								
Weekday	5.3	−0.2	<0.1	<0.001	4.2	−0.2	<0.1	<0.001
Weekend	3.8	−0.2	<0.1	<0.001	3.1	−0.2	<0.1	<0.001
Commute hour								
Morning	5.7	−0.1	<0.1	<0.001	2.7	−0.1	<0.1	0.009
Afternoon	8.7	−0.5	<0.1	<0.001	6.3	−0.3	<0.1	<0.001

vehicle miles driven per licensed driver (14854 vs 14192 in 2010). Reporting criteria also varied by state for property-damage only crashes; however, very few pedestrian crashes result only in property damage. Still, care must be exercised in comparing trends over geography and time, being mindful of changes in data availability and coding practices. For example, in table 1 and figure 1, average annual crash rates in Iowa and Minnesota are based on an early subset of the 15-year period, which may reflect higher rates than those averaged over more recent years. Furthermore, the reliability of crash reports has also been shown to vary by region and crash characteristics[37]; the misclassification of injury severity has also been documented in linkage studies with hospital data.[38 39]

While population-based denominators help to compare crash burdens between states on a per capita basis, they do not account for pedestrian density, a desirable metric that is not always available or practical.[40] We attempted to address this, at least in part, by exploring patterns in the pedestrian danger index adapted from Atherton *et al*[24] using nationally available census data.

CONCLUSION

Youth pedestrian and bicyclist crash rates continued to decline through 2014, even as adult pedestrian and bicyclist crash rates began to rise. Ongoing research should continue to explore the role of growing efforts across the nation, such as SRTS and Vision Zero programme, to help to reduce pedestrian and bicyclist morbidity and mortality in children and adults alongside efforts to promote physical activity and public transportation. Despite challenges inherent in the analysis of state crash data inclusive of non-fatal injuries, which are not standardised from state to state, these data provide a useful resource that allows for the characterisation of the burden of total pedestrian crashes, as well the estimation of non-fatal injury rates, fatal injury rates and crash fatality proportion across a variety of crash characteristics using a denominator of all police-reported crashes.

What is already known on this subject

- Pedestrian and bicyclist crashes are a leading cause of serious injuries in children.
- Recent studies have found beneficial effects of interventions, such as Safe Routes to School, in reducing youth pedestrian risk.

What this study adds

- School-age pedestrians and bicyclists experienced ongoing declines in pedestrian and bicyclist crashes with motor vehicles through 2014, even as adult pedestrian and bicyclist crashes rose.
- State motor vehicle crash data are growing in availability and can be useful in monitoring state and local trends in the full spectrum of pedestrian and bicyclist crashes, including non-fatal outcomes.

Contributors KCW-M acquired, maintained and processed all study data, co-developed the analytic plan, analysed the complete data set, and drafted and revised the paper. AEC contributed to study conceptualisation, review and revision, and supervised data acquisition and processing (CHOP Traffic Safety Data Warehouse). KBM contributed to data analyses (CHOP data), advised on the analytic plan and visualisation, and reviewed the paper. CJDM conceptualised the original study design and methodology, supervised data acquisition and analyses, and reviewed and revised the paper.

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ORCID iDs
Katherine C Wheeler-Martin http://orcid.org/0000-0002-6806-4233
Charles J DiMaggio http://orcid.org/0000-0003-2356-6659

REFERENCES

1 National Highway Traffic Safety Administration. *Traffic safety facts 2016 data-pedestrians*. Washington, DC: National Highway Traffic Safety Administration, 2018.
2 Centers for Disease Control and Prevention. Ten leading causes of death. Available: http://www.cdc.gov/injury/wisqars/LeadingCauses.html [Accessed 9 Mar 2019].
3 National Highway Traffic Safety Administration. *Traffic safety facts 2016 data-children*. Washington, DC, 2018.
4 Levin Martin S, Moeti R, Pullen-Seufert N. Implementing safe routes to school: application for the socioecological model and issues to consider. *Health Promot Pract* 2009;10:606–14.
5 US Department of Health and Human Services. Step it Up! The Surgeon General's Call to Action to Promote Walking and Walkable Communities. Available: http://www.surgeongeneral.gov/library/calls/walking-and-walkable-communities [Accessed 9 Mar 2019].
6 Centers for Disease Control and Prevention. Strategies to prevent obesity and chronic disease: the CDC guide to strategies to increase physical activity in the community. Available: http://www.cdc.gov/physicalactivity/community-strategies/index.htm [Accessed 9 Mar 2019].
7 National Highway Traffic Safety Administration. Fatality analysis system.
8 Merrell GA, Driscoll JONC, Degutis LC, *et al*. Prevention of childhood pedestrian trauma. *J Bone Joint Surg Am* 2002;84:863–7.
9 Hotz G, Kennedy A, Lutfi K, *et al*. Preventing pediatric pedestrian injuries. *J Trauma* 2009;66:1492–9.
10 Alisic E, Zalta AK, van Wesel F, *et al*. Rates of post-traumatic stress disorder in trauma-exposed children and adolescents: meta-analysis. *Br J Psychiatry* 2014;204:335–40.
11 Kassam-Adams N, Marsac ML, Hildenbrand A, *et al*. Posttraumatic stress following pediatric injury: update on diagnosis, risk factors, and intervention. *JAMA Pediatr* 2013;167:1158–65.
12 Zatzick DF, Jurkovich G, Wang J, *et al*. Variability in the characteristics and quality of care for injured youth treated at trauma centers. *J Pediatr* 2011;159:1012–6.
13 Wheeler-Martin K, Mooney SJ, Lee DC, *et al*. Pediatric emergency department visits for pedestrian and bicyclist injuries in the US. *Inj Epidemiol* 2017;4.
14 National Highway Traffic Safety Administration. State data system. Available: http://www.nhtsa.dot.gov/state-data-programs/sds-overview [Accessed 9 Mar 2019].
15 National Highway Traffic Safety Administration. Crash report sampling system. Available: http://www.nhtsa.dot.gov/national-center-statistics-and-analysis-ncsa/crash-report-sampling-system-crss [Accessed 9 Mar 2019].
16 DiMaggio C, Frangos S, Li G. National safe routes to school program and risk of school-age pedestrian and bicyclist injury. *Ann Epidemiol* 2016;26:412–7.
17 California Highway Patrol. Internet statewide integrated traffic records system. Available: http://www.chp.ca.gov/programs-services/services-information/switrs-internet-statewide-integrated-traffic-records-system [Accessed 9 Mar 2018].
18 University of Connecticut - Connecticut Transportation Safety Research Center. Connecticut crash Repository.
19 Texas Department of Transportation. Crash data analysis and statistics. Available: http://www.txdot.gov/government/enforcement/crash-statistics.html [Accessed 9 Mar 2019].
20 Kentucky State Police. Kentucky collision analysis for the public. Available: http://crashinformationky.org [Accessed 9 Mar 2019].
21 US Census Bureau. Population and housing unit estimates. Available: http://www.census.gov/programs-surveys/popest.html [Accessed 9 Mar 2019].
22 US Census Bureau. American community survey. Available: http://www.census.gov/programs-surveys/acs [Accessed 9 Mar 2019].
23 Federal Highway Administration. KABCO injury classification scales and definitions. Available: http://safety.fhwa.dot.gov/hsip/spm/conversion_tbl/pdfs/kabco_ctable_by_state.pdf [Accessed 9 Mar 2019].
24 Atherton E, Chang Y, Davis S, *et al*. Dangerous by design 2016, 2017. Available: https://smartgrowthamerica.org/dangerous-by-design/
25 Gelman A, Hill J. Data analysis using regression and multilevel/hierarchical models 2006.
26 DiMaggio C, Li G. Roadway characteristics and pediatric pedestrian injury. *Epidemiol Rev* 2012;34:46–56.

27 Schneider RJ, Vargo J, Sanatizadeh A. Comparison of US metropolitan region pedestrian and bicyclist fatality rates. *Accid Anal Prev* 2017;106:82–98.
28 Jacobsen PL, Ragland DR, Komanoff C. Safety in numbers for walkers and bicyclists: exploring the mechanisms. *Inj Prev* 2015;21:217–20.
29 Rosén E, Sander U. Pedestrian fatality risk as a function of car impact speed. *Accid Anal Prev* 2009;41:536–42.
30 Mueller BA, Rivara FP, Bergman AB. Urban-Rural location and the risk of dying in a pedestrian-vehicle collision. *J Trauma* 1988;28:91–4.
31 Zhu M, Cummings P, Chu H, *et al*. Urban and rural variation in walking patterns and pedestrian crashes. *Inj Prev* 2008;14:377–80.
31 DiMaggio C, Li G. Effectiveness of a safe routes to school program in preventing school-aged pedestrian injury. *Pediatrics* 2013;131:290–6.
33 Stewart O, Moudon AV, Claybrooke C. Multistate evaluation of safe routes to school programs. *Am J Health Promot* 2014;28(3 Suppl):S89–96.
34 DiMaggio C, Chen Q, Muennig PA, *et al*. Timing and effect of a safe routes to school program on child pedestrian injury risk during school travel hours: Bayesian changepoint and difference-in-differences analysis. *Inj Epidemiol* 2014;1.
35 Muennig PA, Epstein M, Li G, *et al*. The cost-effectiveness of new York City's safe routes to school program. *Am J Public Health* 2014;104:1294–9.
36 DiMaggio C, Ayoung-Chee P, Shinseki M, *et al*. Traumatic injury in the United States: in-patient epidemiology 2000–2011. *Injury* 2016;47:1393–403.
37 Farmer CM. Reliability of police-reported information for determining crash and injury severity. *Traffic Inj Prev* 2003.
38 Lopez DG, Rosman DL, Jelinek GA, *et al*. Complementing police road-crash records with trauma registry data--an initial evaluation. *Accid Anal Prev* 2000;32:771–7.
39 Tsui KL, So FL, Sze NN, *et al*. Misclassification of injury severity among road casualties in police reports. *Accid Anal Prev* 2009;41:84–9.
40 Injury Surveillance Workgroup 8 (ISW8). Consensus recommendations for pedestrian injury surveillance. Atlanta, GA. Available: http://c.ymcdn.com/sites/www.safestates.org/resource/resmgr/ISW8_Report_Final.pdf