An examination of the increases in pedestrian motor vehicle crash fatalities during 2009–16

May 2018

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Abstract

Introduction: Pedestrian fatalities increased 46% in the United States during 2009–16. This study identified circumstances under which the largest increases in deaths occurred during this period.

Method: Annual counts of U.S. pedestrian fatalities and crash involvements were extracted from the Fatality Analysis Reporting System and General Estimates System. Poisson regression examined if pedestrian fatalities by various roadway, environmental, personal, and vehicle factors changed significantly during 2009–16. Linear regression examined changes over the study period in pedestrian deaths per 100 crash involvements and in horsepower per 1,000 pounds of weight among passenger vehicles involved in fatal single-vehicle pedestrian crashes.

Results: Pedestrian deaths per 100 crash involvements increased 29% from 2010, when they reached their lowest point, to 2015, the most recent year for which crash involvement data were available. The largest increases in pedestrian deaths during 2009–16 occurred in urban areas (54% increase from 2009 to 2016), on arterials (67% increase), at nonintersections (50% increase), and in dark conditions (56% increase). The rise in the number of SUVs involved in fatal single-vehicle pedestrian crashes (82% increase) was larger than the increases in the number of cars, vans, pickups, or medium/heavy trucks involved in these crashes. The power of passenger vehicles involved in fatal single-vehicle pedestrian crashes increased over the study period, with larger increases in vehicle power among more powerful vehicles.

Conclusions: Efforts to turn back the recent increase in pedestrian fatalities should focus on the conditions where the rise has been the greatest.

Practical applications: Transportation agencies can improve urban arterials by investing in proven countermeasures, such as road diets, median crossing islands, pedestrian hybrid beacons, and automated speed enforcement. Better road lighting and vehicle headlights could improve pedestrian visibility at night.

Keywords: pedestrians, fatalities, Fatality Analysis Reporting System (FARS)

1. Introduction

Walking as a means of transportation has increased in recent years. According to the American Community Survey, the estimated number of Americans who reported walking as their primary method of commuting to work in the past week increased from 3.3 million in 2005 to 4.2 million in 2015 (U.S. Census Bureau, 2005, 2015). Walking provides health, traffic, and environmental benefits (America Walks, 2017). Unfortunately, pedestrians are among the road users who are at the most at risk in traffic, and they represent a considerable portion of motor vehicle crash injuries and deaths. In 2016, 5,987 pedestrians were killed in motor vehicle crashes on public roadways in the United States (Insurance Institute for Highway Safety [IIHS], 2017a).

Although pedestrian deaths in 2016 were 20% lower than in 1975, they have increased since reaching their lowest point in 2009. Pedestrian deaths rose by 46% from 2009 to 2016. In contrast, the number of other motor vehicle crash deaths increased 6% during this period, after declining during 2009–2014 and then increasing again in 2015 and 2016. Pedestrian deaths, as a portion of the total motor vehicle crash deaths, jumped from 12% in 2009 to 16% in 2016, which is the largest proportion of traffic fatalities they have comprised in 30 years.

The recent upward trend in pedestrian fatalities is concerning. Although the recent rise in pedestrian fatalities has been discussed elsewhere (Retting, 2017), little investigation has been done into how trends varied by roadway, environmental, personal, and vehicle factors. The goal of the current study was to examine the circumstances where pedestrian fatalities have experienced the largest increases during 2009–16. Countermeasures to improve pedestrian safety should focus on these circumstances. The findings could help transportation agencies identify and prioritize areas with the highest potential, to stem the rising number of pedestrian fatalities and develop effective pedestrian safety strategies.

2. Method

2.1 Data

Data on pedestrian fatalities in motor vehicle crashes were extracted for 2009–16 from the Fatality Analysis Reporting System (FARS), which contains detailed information on all fatal motor vehicle crashes occurring on U.S. public roads. Annual counts of pedestrian fatalities were obtained. Annual numbers of pedestrians involved in crashes regardless of injury levels were obtained for 2009–15 from the National Automotive Sampling System/General Estimates System (NASS/GES), which is a nationally representative sample of police-reported motor vehicle crashes. The 2016 number of pedestrians involved in all crashes was not available at the time of the study.

By using the data extracted from FARS, annual counts of pedestrian fatalities by land use (urban vs. rural), road functional class (interstates and freeways, arterials, and collectors and local roads), location (at intersections vs. nonintersections), light condition (daylight, dawn or dusk, and dark), and personal characteristics (age, gender, and blood alcohol concentration (BAC)) were obtained for each year during 2009–16. Counts of fatalities by BAC are only reported for those age 16 and older, because few younger fatally injured pedestrians are alcohol impaired. The FARS dataset includes BACs from alcohol tests, as well as imputed BACs when the actual BAC was not reported. Subramanian (2002) describes the methods used for imputing missing values. All reported findings were based on actual and imputed BACs. About 5% of land use and road functional class values were unknown in 2015 and 2016, a relatively large proportion compared with years 2009–14. Counts with unknown values were allocated to counts by land use and road functional class based on distribution of known values for years 2009–16.

Annual U.S. population estimates as well as the population by age and gender for 2009–16 were obtained from the U.S. Census Bureau. These data were used to calculate annual overall per capita pedestrian death rates and crash involvement rates as well as per capita death rates by age and gender.

Vehicles in fatal single-vehicle pedestrian crashes during 2009–16 were identified from FARS data. Annual counts of vehicles involved by vehicle type were obtained. The vehicle identification numbers (VINs) of these vehicles recorded in FARS were decoded, in conjunction with FARS vehicle body type codes, to obtain vehicle type (cars, minivans or large vans, pickups, SUVs, medium/heavy trucks, and other vehicle types), horsepower, and weight from vehicle information databases maintained by the Highway Loss Data Institute (HLDI). Vehicle type was unknown for 8–9% of these vehicles. Other vehicle types, such as buses, motorcycle-like vehicles, all-terrain vehicles, and motor homes, accounted for about 1% of the identified vehicles, and were not included in the analysis. Horsepower and weight were available for passenger vehicles only. The horsepower for 2–4% of the identified passenger vehicles was missing every year. Power-to-weight ratio was calculated as the horsepower divided by the vehicle weight per 1,000 lbs. The power-to-weight ratio percentiles (10th, 25th, 50th, 75th, and 90th percentile) of the passenger vehicles in these crashes were calculated annually.

2.2 Analyses

Poisson regression analyses were performed to examine if annual changes in pedestrian fatalities over the study period were significant. Time trends were tested within each of the factors examined by fitting separate Poisson models for each category of the factor, with the annual pedestrian death count as the dependent variable and the number of years since 2008 as the independent variable. The number of years parameter was used to estimate the average annual change in pedestrian deaths during 2009–16. For example, for the analyses of pedestrian fatalities by land use, the estimated parameter for the number of years was 0.0596 in the urban model and 0.0225 in the rural model. Based on these parameters, the estimated average annual increase in pedestrian deaths during 2009–16 was 6.1% ($[\exp(0.0596) - 1] \times 100$) in urban areas, and 2.3% ($[\exp(0.0225) - 1] \times 100$) in rural areas. Similar Poisson regression analyses were performed to estimate the average annual changes in counts of vehicles involved in fatal single-vehicle pedestrian crashes by vehicle type.

For analyses of overall pedestrian fatalities, annual population was included as the exposure variable (log of population included as an offset term). Similarly, annual population by age and gender was included as the exposure variable in models of pedestrian fatalities by age and gender. For other factors examined, no exposure variable was included in the analyses. Vehicle miles traveled (VMT) was initially included as a covariate in the overall pedestrian fatality model as well as models by land use and road functional class. However, VMT was not significant in any of the models and thus not included in the final models. Variables with p-values less than 0.05 were taken as statistically significant.

If the estimated annual change in pedestrian fatalities was significant for more than one category of a factor, additional Poisson models were estimated to examine if the changes differed significantly between the categories, by including and testing an interaction between the factor and time. For example, a Poisson regression model was estimated to test if the annual increases in pedestrian deaths differed between urban and rural areas. The estimated parameter of the interaction term between the number of years and the urban area indicator was 0.0372 with a *p*-value of 0.0011. Based on this estimate, the annual increase in urban areas was 3.8% ($[\exp(0.0372) - 1] \times 100$) significantly higher than in rural areas.

A linear regression analysis of the annual pedestrian deaths per 100 crash involvements with the number of years as the independent variable was also performed, to examine if pedestrian crashes became deadlier during the study period. Similarly, separate linear regression analyses of annual percentiles of passenger vehicle power-to-weight ratio in fatal single-vehicle pedestrian crashes were performed with the number of years as the independent variable, which tested whether vehicles got more (or less) powerful over the study period. To examine if the annual changes in power-to-weight ratio differed by percentile, additional linear regression analyses were performed with the number of years, a percentile indicator, and an interaction between the number of years and the percentile indicator as the independent variables. The interaction term tested whether the average annual changes in power-to-weight ratio of different percentiles were different.

3. Results

3.1 Overall pedestrian fatality trend

From 2009 to 2016, the number and per capita rate of pedestrian deaths increased 46% and 38%, respectively (Table 1). From 2009 to 2015, the number and per capita rate of pedestrians involved in all police-reported crashes increased more slowly than pedestrian deaths (19% and 13% vs. 34% and 28%, respectively). Poisson regressions estimated a 4.4% average annual increase in pedestrian deaths per capita during 2009–16 and a 0.5% average annual increase in pedestrian crash involvements per capita during 2009–15. Only the increase in the fatality rates was significant ($p<0.0001$).

During 2009–15, pedestrian deaths per 100 pedestrians involved in all crashes reached the lowest point in 2010 and have generally increased since then. From 2010 to 2015, deaths per 100 pedestrians involved in all crashes increased 29%. A linear regression model estimated a significant average annual increase of 0.34 deaths per 100 involved during 2010–15 (*p*=0.0035).

Table 1. Pedestrians involved in motor vehicle crashes of all severities and fatally injured pedestrians, numbers and per capita rates, 2009–16

		Pedestrians involved in all crashes		Fatally injured pedestrians		
Year	Population	Number	Rate per million population	Number	Rate per million population	Deaths per 100 involved
2009	307,006,550	62,094	202.3	4,109	13.4	6.6
2010	308,745,538	74,649	241.8	4,302	13.9	5.8
2011	311,591,917	75,000	240.7	4,457	14.3	5.9
2012	313,914,040	81,837	260.7	4,818	15.3	5.9
2013	316,128,839	72,478	229.3	4,779	15.1	6.6
2014	318,857,056	71,732	225.0	4,910	15.4	6.8
2015	321,418,820	73,599	229.0	5,495	17.1	7.5
2016	323,127,513	N/A	N/A	5,987	18.5	N/A
Percent change from 2009–15*	5%	19%	13%	34%	28%	13%
Percent change from 2009–16	5%	N/A	N/A	46%	38%	N/A

*: The number of pedestrians involved in all crashes in 2016 was not available at the time of the study. The percentage changes from 2009 to 2015 are presented for comparison.

3.2 Pedestrian fatality trend by roadway and environmental factors

More than two thirds of pedestrian deaths during 2009–16 occurred in urban areas, away from intersections, or in the dark, and more than half occurred on arterials (Table 2). From 2009 to 2016, pedestrian deaths on arterials increased 67%; in dark conditions increased 56%; in urban areas increased 54%; and at nonintersection locations increased 50%.

Poisson models estimated that there was a significant 6.1% average annual increase in pedestrian deaths in urban areas and a significant 2.3% increase in rural areas. The increase in urban areas was an estimated 3.8% higher than in rural areas, and the difference was significant (*p*=0.0011). Annually, pedestrian deaths increased significantly on arterials (7.5%) and on interstates and freeways (4.9%), and increased but nonsignificantly on collectors and local roads (1.0%). The increase on arterials was an estimated 2.5% higher than on interstates and freeways, but the difference was not significant.

Average annual increases in deaths were significant at nonintersections (5.4%) and intersections (4.6%), and did not differ significantly from each other. Average annual increases were significant under all light conditions, with the largest increase in the dark (6.1%) and the smallest increase in the daylight (2.7%). Increases did not differ significantly between daylight and dawn/dusk conditions. The increase under dark conditions was 3.1% higher than under the daylight and dawn/dusk conditions combined, and the difference was significant (*p*=0.0011).

Table 2. Pedestrian deaths by roadway and environmental factors, 2009–16, and estimated average annual changes in deaths by factors from Poisson regressions

Factor	2009	2010	2011	2012	2013	2014	2015	2016	Change from 2009 to 2016		Average annual change$^+$
									Number	Percentage	
Land use											
Urban	2,959	3,149	3,282	3,548	3,507	3,815	4,239	4,546	1,587	54%	6.1%*
Rural	1,150	1,153	1,175	1,270	1,272	1,095	1,256	1,441	291	25%	2.3%*
Functional class											
Interstates and freeways	618	686	690	674	706	713	821	923	305	49%	4.9%*
Arterials	2,183	2,226	2,368	2,599	2,488	2,770	3,223	3,640	1,457	67%	7.5%*
Collectors and local roads	1,308	1,390	1,399	1,544	1,584	1,427	1,452	1,426	118	9%	1.0%
Location											
Intersection	1,132	1,108	1,134	1,254	1,214	1,260	1,431	1,528	396	35%	4.6%*
Nonintersection	2,967	3,194	3,323	3,564	3,565	3,650	4,064	4,459	1,492	50%	5.4%*
Light condition											
Daylight	1,079	1,092	1,068	1,168	1,166	1,191	1,245	1,290	211	20%	2.7%*
Dawn or dusk	162	161	162	177	181	185	188	205	43	27%	3.5%*
Dark	2,846	3,030	3,204	3,452	3,405	3,510	4,041	4,453	1,607	56%	6.1%*

+Estimated from Poisson regression results; **p*<0.05

3.2.1 Pedestrian fatality trend by roadway factors in urban and rural areas

Because trends in pedestrian deaths differed by land use, trends by roadway factors were examined separately in urban and rural areas (Table 3). In urban areas, more than two thirds of pedestrian deaths occurred at nonintersections, and over half occurred on arterials. From 2009 to 2016, pedestrian deaths increased 69% on arterials and 59% at nonintersections in urban areas. In rural areas, 37–54% of pedestrian deaths occurred on arterials and more than 80% occurred at nonintersections every year during the study period. From 2009 to 2016, pedestrian deaths increased 59% on arterials and 32% at nonintersections in rural areas.

Trends in urban areas were similar to overall trends. Urban deaths increased significantly on each road functional class, with the highest average annual increase on arterials (7.7%). The annual increase on arterials was an estimated 3.0% higher than on interstates and freeways (*p*=0.0858) and 4.0% higher than on collectors and local roads (p=0.0173). There were significant average annual increases in pedestrian deaths at both nonintersections (6.6%) and intersections (5.2%), and these increases did not differ significantly.

In rural areas, there were significant average annual increases on interstates and freeways (6.2%) and on arterials (6.8%), and a significant annual decrease on collectors and local roads (-3.6%). The increase on interstates and freeways did not differ significantly from the increase on arterials. Pedestrian deaths declined annually on average at intersections, but not significantly (-0.2%). There was a significant 2.7% annual increase at nonintersections.

Table 3. Pedestrian deaths by roadway factors in urban and rural areas, 2009–16, and estimated average annual changes in deaths by factors from Poisson regressions

Factor	2009	2010	2011	2012	2013	2014	2015	2016	Change from 2009 to 2016		Average annual change$^+$
									Number	Percentage	
Urban roads											
Functional class											
Interstates and freeways	494	541	548	530	520	570	652	708	214	43%	4.5%*
Arterials	1,691	1,796	1,845	2,030	1,913	2,218	2,583	2,856	1,165	69%	7.7%*
Collectors and local roads	767	808	883	980	1,071	995	991	967	200	26%	3.6%*
Location											
Intersection	966	973	994	1,110	1,067	1,143	1,270	1,374	408	42%	5.2%*
Nonintersection	1,990	2,175	2,287	2,439	2,440	2,672	2,969	3,172	1,182	59%	6.6%*
Rural roads											
Functional class											
Interstates and freeways	122	144	139	142	185	136	166	213	91	74%	6.2%*
Arterials	487	426	513	561	571	526	630	773	286	59%	6.8%*
Collectors and local roads	538	580	510	559	511	418	457	453	-85	-16%	-3.6%*
Location											
Intersection	166	135	140	144	147	117	161	154	-12	-7%	-0.2%
Nonintersection	977	1,019	1,036	1,125	1,125	978	1,095	1,287	310	32%	2.7%*

+Estimated from Poisson regression results; *p<0.05

Trends in pedestrian fatalities at intersections and nonintersections were also examined for the various land use and functional class combinations (Table 4). Fatalities were more frequent at nonintersections than at intersections on each roadway type. From 2009 to 2016, among the scenarios shown in Table 4, the highest increase in pedestrian deaths occurred at nonintersections on urban arterials, which represented 51% of the total increase in urban areas (803/1,587). There were significant estimated average annual increases at both intersections and nonintersections for all land use and road functional class combinations except on rural collectors and local roads, where there were significant decreases at both intersections and nonintersections, and at intersections on urban collectors and local roads, where the average annual increase did not reach significance. On urban arterials, on urban collectors and local roads, and on rural arterials, the increases were larger at nonintersections than at intersections, although not significantly so.

Table 4. Pedestrian deaths by crash locations by land use and road functional class, 2009–16, and estimated average annual changes in deaths by factors from Poisson regressions

Factor	2009	2010	2011	2012	2013	2014	2015	2016	Change from 2009 to 2016		Average annual change+
									Number	Percentage	
Urban roads											
Interstates and freeways++											
Intersection	35	23	19	25	9	21	20	15	--	--	
Nonintersection	459	518	529	505	511	549	632	693	234	51%	5.1%*
Arterials											
Intersection	677	678	657	726	664	777	932	1,040	363	54%	6.6%*
Nonintersection	1,013	1,118	1,189	1,305	1,249	1,442	1,651	1,816	803	79%	8.3%*
Collectors and local roads											
Intersection	254	276	315	360	393	328	331	330	76	30%	3.3%
Nonintersection	512	532	568	620	678	668	659	637	125	24%	3.7%*
Rural roads											
Interstates and freeways++											
Intersection	3	1	0	0	1	0	0	0	--	--	
Nonintersection	119	143	139	142	184	136	166	213	94	78%	6.4%*
Arterials											
Intersection	76	60	79	71	85	65	101	98	22	28%	5.1%*
Nonintersection	406	365	434	490	486	461	529	675	269	66%	7.2%*
Collectors and local roads											
Intersection	86	72	58	72	59	52	54	46	-40	-46%	-7.4%*
Nonintersection	449	507	452	487	452	366	402	407	-42	-9%	-3.0%*

+Estimated from Poisson regression results; * $p<0.05$

++ Intersection crashes on interstates/freeways did not occur within interchanges; these are likely coding errors.

3.3 Pedestrian fatality trend by personal characteristics

Pedestrians 70 years and older had the highest per capita death rates among all age groups examined (Table 5). There were significant average annual increases in death rates of pedestrians ages

20–29 (3.8%), 30–59 (5.1%), 60–69 (5.6%), and 70 and older (1.6%). Death rates declined for pedestrians under age 13 and increased for ages 13–19, although not significantly so. Annual increases in death rates did not differ significantly among the age groups 20–29, 30–59, and 60–69. The average annual increase in the death rate of the combined age group 20–69 was 3.3% higher than age group 70 and older (*p*=0.0062). Per capita pedestrian death rates were higher for males than females. Rates increased significantly per year for both males (4.6%) and females (3.7%), and increases did not differ significantly by gender.

Among fatally injured pedestrians age 16 and older, about 60% had BACs of 0.00 g/dL, over a third had BACs of 0.08 g/dL or above, and about 5% had BACs between 0.01 and 0.07 g/dL every year. Average annual increases in pedestrian deaths were significant at all BAC levels. The annual increase among pedestrians with BACs of 0.00 g/dL was significantly 1.7% higher than those with BACs at or above 0.08 g/dL (*p*=0.0292). Increases did not differ significantly between those with BACs of 0.00 g/dL and with BACs between 0.01 and 0.07 g/dL.

Table 5. Pedestrian deaths by personal factors, 2009–16, and estimated average annual changes by factors from Poisson regressions

Factor	2009	2010	2011	2012	2013	2014	2015	2016	Change from 2009 to 2016		Average annual change^{+}
									Number	Percentage	
Death rates per million population											
Age											
<13	3.7	4	3.2	3.9	3.9	3.2	3.5	3.7	0	<1%	-0.9%
13–19	8.7	9.7	10	9.8	8.2	9.1	9.5	10.9	2.2	25%	1.2%
20–29	14.1	15.9	16.1	17.4	16.5	16.7	18.5	19.7	5.6	40%	3.8%*
30–59	16.1	16	16.8	17.8	18.2	18.1	21.1	22.7	6.6	41%	5.1%*
60–69	15.8	15.6	16.9	18	18	19.3	21.2	22.7	6.9	44%	5.6%*
70+	20.8	22.6	22.3	24.2	22.1	23.6	22.7	24.8	4	19%	1.6%*
Gender											
Male	18.7	19.5	20.2	21.6	21.1	21.8	24.2	26.3	7.6	40%	4.6%*
Female	8.2	8.5	8.6	9.3	9.3	9.1	10.1	10.9	2.7	33%	3.7%*
Total number of deaths by BAC, ages 16+											
0.00 g/dL	2,237	2,386	2,435	2,655	2,700	2,834	3,172	3,422	1,185	53%	6.1%*
0.01–0.07 g/dL	173	192	196	220	193	199	239	278	105	61%	5.5%*
≥ 0.08 g/dL	1,401	1,410	1,544	1,626	1,586	1,596	1,772	1,938	537	38%	4.3%*

+Estimated from Poisson regression results; *p<0.05

3.4 Vehicle characteristics in fatal single-vehicle pedestrian crashes

3.4.1 Vehicle type

About 90% of fatal pedestrian crashes were single-vehicle crashes during 2009–16, and in these crashes, the most common vehicle type involved were cars (Table 6). There were significant annual increases in fatal crashes involving cars (5.1%), pickups (4.3%), SUVs (7.9%), and medium or heavy trucks (4.3%). Fatal crashes involving minivans and large vans did not increase significantly. The estimated annual increases did not differ significantly among cars, pickups, and medium or heavy trucks. The average annual increase in crashes involving SUVs was 3.1% higher than the increase in other vehicle types combined, and the difference was significant (*p*=0.0091).

Table 6. Vehicles by type in fatal single-vehicle pedestrian crashes, 2009–16, and estimated average annual changes from Poisson regressions

Vehicle type++	2009	2010	2011	2012	2013	2014	2015	2016	Change from 2009 to 2016		Average annual change+
									Number	Percentage	
Cars	1,461	1,457	1,538	1,761	1,628	1,694	1,969	2,062	601	41%	5.1%*
Minivans and large vans	275	290	289	293	270	300	282	317	42	15%	1.1%
Pickups	651	665	669	708	738	766	819	862	211	32%	4.3%*
SUVs	637	701	742	784	786	835	959	1156	519	81%	7.9%*
Medium or heavy trucks	182	176	202	188	222	205	229	241	59	32%	4.3%*

+Estimated from Poisson regression results; *$p<0.05$; ++Other vehicle types, such as buses and motorcycles, accounted for about 1% of the identified vehicles and were not included in the analysis.

3.4.2 Vehicle power-to-weight ratio

About 84% of vehicles involved in fatal single-vehicle pedestrian crashes during the study period were passenger vehicles. The power-to-weight ratio of these passenger vehicles by percentile (10th, 25th, 50th, 75th, and 90th percentile) is summarized in Table 7. Linear regression models found that the 10th, 25th, 50th, 75th, and 90th percentile power-to-weight ratio all increased significantly over the study period, and the increase was generally higher among vehicles with more power. The annual increase in the 50th percentile power-to-weight ratio was 0.13 units higher than the increase in the 25th percentile (*p*=0.0125); the increase in the 75th percentile was 0.11 units higher than the increase in the 50th percentile (*p*=0.0442);

and the increase in the 90th percentile was 0.38 units higher than the increase in the 75th percentile (*p*=0.0014). The increases in the 10th and 25th percentile did not differ significantly.

Table 7. Power-to-weight ratio of passenger vehicles by percentile in fatal single-vehicle pedestrian crashes, 2009–16, and estimated average annual changes from linear regressions

Horsepower per 1,000 lb. vehicle weight by percentile	2009	2010	2011	2012	2013	2014	2015	2016	Percent change, 2009–16	Average annual change+
10th percentile	41.8	41.5	42.4	42.8	42.7	43.3	43.5	44.0	5%	0.33*
25th percentile	45.7	45.5	45.9	46.7	46.8	47.5	47.5	48.0	5%	0.37*
50th percentile	50.4	50.5	51.1	51.6	51.9	52.7	53.3	53.7	7%	0.50*
75th percentile	56.4	56.6	57.1	58.2	58.6	59.1	59.5	60.8	8%	0.62*
90th percentile	62.9	63.6	63.9	65.8	65.6	67.2	68.5	69.9	11%	0.99*

+Linear regression results; *$p<0.05$

4. Discussion

The recent upward trend in pedestrian fatalities has urged transportation agencies to take action to improve pedestrian safety. The current study examined the most recent trends in pedestrian fatalities by characteristics of roads, environment, pedestrians, and vehicles, and identified circumstances where significant increases occurred during 2009–16. Increases in pedestrian fatalities occurred in nearly all circumstances examined, but the largest increases were seen in conditions under which the highest numbers of pedestrian deaths have historically occurred: in urban areas, on arterials, away from intersections, and in the dark. The rise in the number of SUVs involved in fatal single-vehicle pedestrian crashes was larger than the increases for other vehicle types. Power-to-weight ratio of passenger vehicles involved in fatal single-vehicle pedestrian crashes rose, with larger increases among more powerful vehicles. Per capita death rates increased the most for pedestrians ages 20–69.

Arterials are typically multilane roads with higher speeds and traffic volumes, and have long been problematic for pedestrians (Zegeer, Nabors, Gelinne, Lefler, & Bushnell, 2010). Communities, and those in urban areas in particular, should focus efforts on countermeasures to improve pedestrian safety on arterials. Countermeasures such as curb extensions and median crossing islands that reduce the crossing distance for pedestrians are effective at intersections and midblock crossings (Gårder, 1989; Retting, Ferguson, & McCartt, 2003; Zegeer, Stewart, Huang, & Lagerwey, 2001). The majority of pedestrian deaths on arterials occurred at nonintersections. Providing designated midblock crossing locations that alert drivers to the presence of pedestrians, such as with pedestrian hybrid beacons, can increase driver yielding to pedestrians and reduce pedestrian crashes (Brewer, Fitzpatrick, & Avelar, 2015; Fitzpatrick & Park, 2009). Adding sidewalks or other walkways to roads without them can reduce nonintersection crashes involving pedestrians walking along roadways (McMahon, Duncan, Stewart, Zegeer, & Khattak, 1999).

Vehicle speed can be an issue for pedestrians on all road types, including arterials. Effective countermeasures to reduce speeds include traffic calming devices, automated speed enforcement, and roundabouts (Hu & McCartt, 2016; Retting et al., 2003; Retting, Kyrychenko, & McCartt, 2008; Retting, Persaud, Garder, & Lord, 2001). Road diets, or roadway reconfigurations that usually reduce the number of travel lanes, can reduce speeds and the number of lanes required for pedestrians to cross while providing operational benefits, such as reducing delays at signalized intersections and at side streets for vehicles turning onto the main roadway (Knapp et al., 2014); road reconfigurations can include adding median crossing islands, curb extensions, or sidewalks.

Several hundred pedestrian fatalities occurred on interstates and freeways every year during 2009–2016. Due to the lack of pedestrian facilities and high-speed traffic, pedestrians are extremely vulnerable on these roads. Countermeasures designed to safely accommodate pedestrians are generally not applicable to these roads (AAA Foundation for Traffic Safety, 2014). More research is needed to identify and evaluate countermeasures to keep pedestrians off these roads or to accommodate unintended pedestrians when their vehicles are disabled.

Roadway lighting can improve the visibility of pedestrians at night (Wanvik, 2009). Although headlights are an old technology, the headlight rating program from the Insurance Institute for Highway Safety (2016) has demonstrated that there is great variability among vehicles in the amount of illumination their headlights provide. Recent advances in headlight technology, such as high-intensity discharge lamps, curve-adaptive headlights that swivel around curves, and high-beam assist that automatically switches between high and low beams depending on the presence of traffic, can potentially make pedestrians easier to see in the dark (Reagan, Brumbelow, & Frischmann, 2015; Reagan & Brumbelow, 2017; Reagan, Brumbelow, Flannagan, & Sullivan, 2017).

Other vehicle technologies beyond improved headlights also can mitigate or prevent crashes with pedestrians. Forward collision warning systems with automatic emergency braking continuously monitor traffic in front of vehicles, warn drivers of potential collisions, and brake the vehicle if a driver does not respond. Some systems can recognize pedestrians. A recent study found that Subaru vehicles with an automatic emergency braking system designed to detect pedestrians had insurance claim rates in pedestrian injury crashes that were 35% lower than among the same vehicle models without the system; claims were assumed to be from pedestrian crashes if they involved an injury liability claim without a claim for vehicle damage (HLDI, 2017). However, the effectiveness of these systems in preventing pedestrian deaths depends on how they function at high speeds or in low light environments (Jermakian & Zuby, 2011), where both a large majority of and high increases in pedestrian fatalities occurred. In low-speed situations, rearview cameras can prevent backover crashes, in which drivers back into pedestrians. A study found that the odds of a vehicle being involved in a backover crash were 41% lower for vehicle models with rearview cameras as standard features compared with vehicles where backing assistance systems were optional or unavailable (Keall, Fildes, & Newstead, 2017). Rear automatic braking has been particularly effective in reducing backing crashes (Cicchino, 2018). While currently-available rear automatic braking systems are not designed to detect pedestrians, future designs could potentially mitigate or avoid backover crashes in low-speed situations.

Pedestrians age 70 and older have the highest per capita death rates, which can be attributed to slower crossing speeds, age-related declines in the ability to identify safe gaps in traffic, and greater fragility among older adults when struck (Dommes, Cavallo, & Oxley, 2013; Oxley, Fildes, Ihsen, Charlton, & Day, 1997; Rosén & Sander, 2009). The highest increase in per capita pedestrian death rates, however, occurred among prime-age adults ages 20–69. It is unclear why fatality increases were largest among this age range, but a possible reason is more walking among adults in this age range. Previous research has found that alcohol impairment is most prevalent among fatally injured pedestrians ages 21–

59, among whom 43–49% had BACs of 0.08 g/dL or above during 2010–2014 (Eichelberger, McCartt, & Cicchino, 2018). Yet, in the current study, the increase in the number of fatally injured pedestrians with BACs of 0.08 g/dL or above was lower than those with BACs of 0.00 g/dL or between 0.01 and 0.07 g/dL. This finding indicates that there were factors other than alcohol impairment contributing to the growing fatalities among prime-aged pedestrians. Still, alcohol-impaired pedestrian deaths increased significantly, and more work needs to be done to mitigate this problem.

Fatal single-vehicle pedestrian crashes involving SUVs increased more than those involving other vehicle types. The popularity of SUVs has risen in recent years. According to an analysis of U.S. vehicle registration data obtained from IHS Markit, the number of registered SUVs increased 37% from 2009 to 2016, while the number of other registered passenger vehicles decreased by less than 1%. Although larger, heavier vehicles provide more protection to their occupants and thus have lower driver death rates per registered vehicle than smaller cars (IIHS, 2017b), previous research has found that SUVs and other light trucks and vans were associated with increased risks of severely injuring or killing pedestrians in an impact when compared with cars (Lefler & Gabler, 2004; Roudsari, Mock, & Kaufman. 2004). Changes in the front-end design of these vehicles would help reduce the severity of pedestrian injuries in an impact (Hu & Klinich, 2012; Lefler & Gabler, 2004; Roudsari et al, 2004).

Passenger vehicles involved in fatal single-vehicle pedestrian crashes have become more powerful, and the increase in the power-to-weight ratio was higher among more powerful vehicles. The average power-to-weight ratio of all the registered passenger vehicles, which were calculated based on vehicle registration data from IHS Markit and the HLDI vehicle information databases, had similar trends. Previous research found that higher vehicle power was associated with increased vehicle speed and a greater likelihood of a vehicle speeding (McCartt & Hu, 2017). The current trend toward more powerful vehicles may be contributing to higher speeds and as a result, more pedestrian crashes and more severe pedestrian injuries (National Highway Traffic Safety Administration, 1999; Tefft, 2013). The increasing popularity of SUVs and higher vehicle speeds associated with more powerful vehicles could have contributed to how crashes involving pedestrians have become deadlier.

Increasing distraction among pedestrians or drivers has been cited as a possible contributing factor to rising pedestrian deaths (Retting, 2017). However, it has been documented that distraction is not fully or consistently recorded in FARS and other police crash databases (McCartt, Kidd, & Teoh, 2014). Because coding of distraction is unreliable, the current study did not examine fatalities by pedestrian or driver distraction. It is worth noting that while observational studies have documented unsafe crossing behaviors among pedestrians interacting with cell phones or listening to music (Bungum, Day, & Henry, 2005; Thompson, Rivara, Ayyagari, & Ebel, 2013), these studies have generally observed pedestrians crossing at signalized intersections during daylight, which was not among the scenarios with the highest increases in pedestrian fatalities. It is unknown how frequently drivers or pedestrians are distracted at night, how often pedestrians are distracted while crossing arterials at midblock, or how pedestrian or driver distraction in these high-risk situations have changed over time.

This study is not without limitations. Factors that might have contributed to the increases were not rigorously examined, mainly due to the unavailability of pedestrian exposure data. In 2015 and 2016, land use and road functional class were unknown for a relatively large proportion of pedestrian fatality records in FARS when compared with earlier years. For analyses, counts with unknown values were allocated to total counts by land use and road function class based on the distribution of known values for years 2009–16. It is unclear how closely the calculated numbers reflect the actual distributions.

Pedestrian fatalities have increased precipitously since reaching their lowest point in 2009. To have the largest effect in halting the escalation in pedestrian fatalities, countermeasures should be implemented where the rise in fatalities has been greatest. Specifically, transportation agencies can concentrate efforts on improving urban arterials, which represented nearly two thirds of the increase in fatalities during 2009–2016 and on which about half of pedestrian fatalities occurred in 2016. Auto manufacturers can equip vehicles with headlights that do a better job of illuminating pedestrians to prevent crashes that occur in the dark, and with front crash prevention systems that reliably detect pedestrians. Zeroing in on these opportunities will result in the highest potential to improve pedestrian safety.

Acknowledgements

This work was supported by the Insurance Institute for Highway Safety.

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