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Journal

Annals of Epidemiology, 28(25)

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Publication Date

2018-05-01

Data Availability

The data associated with this publication are not available for this reason: disclosure governed by data use agreement

Peer reviewed

Firearm mortality in California, 2000-2015: the epidemiologic importance of within-state variation

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ABSTRACT

Purpose: Firearm mortality is a significant problem in the United States. Previous studies have largely focused on firearm mortality at the national or state-level, leaving open the question of within-state variation. This study examined firearm mortality within California.

Methods: We used Multiple Cause of Death Data Files to identify all firearm fatalities in California from 2000-2015. We described firearm mortality rates and counts over time, by age and county, stratifying by intent, gender, and race/ethnicity. County-level rates were smoothed with empirical Bayes estimates from random-effect Poisson models.

Results: From 2000-2015, there were 24,922 firearm homicides and 23,682 firearm suicides in California. Rates of firearm homicide decreased 30% and suicide rates increased 1% since the mid-2000s, but these trends varied substantially by county. Due to a decline in firearm homicides in metropolitan areas, there was no significant difference in rates between urban and rural counties by 2015. Non-Hispanic black men had the highest rate of firearm homicide, but Hispanic men had the greatest number of deaths.

Conclusions: We found considerable intrastate variation in firearm mortality in California. Our results will be of interest to researchers, policymakers, and public health practitioners. Similar epidemiologic profiles of firearm mortality are warranted for other states.

Keywords: Firearms, Mortality, California, Epidemiology

List of Abbreviations:

US, United States

MCOD, Multiple Cause of Death Data Files

LA, Los Angeles

RR, Relative Risk

CI, Confidence Interval

INTRODUCTION

Firearm-related deaths, injuries, and crimes constitute a significant public health and public safety problem in the United States (US). However, this problem does not affect the entire country uniformly. To the contrary: in 2015 there was more than a 10-fold variation in both firearm suicide and homicide rates across the 50 states.[1] Studies relying on state-level data have sought to explain this interstate variation, relating it to variation in the prevalence of firearm ownership, laws regulating the ownership and use of firearms, and other factors pertaining only indirectly to firearms.[2-4]

Relatively little attention has been given to within state variation in the epidemiology of firearm-related deaths and injuries. This is an important gap in our knowledge. For many years, states, rather than the federal government, have been the principal locus for policies and programs affecting the ownership and use of firearms. Many public health and law enforcement interventions are designed and implemented at the local level.

Within state epidemiologic profiles can provide proactive guidance for policy and program development by specifying which populations and geographic areas are at increased absolute and relative risk. We present here such a profile for California, the most populous state in the country and among the most racially and geographically diverse.[5] We examine firearm mortality over 16 years, describing its change over time and distribution among the population and throughout the state. Our objectives are to provide data that will be of direct use to policy makers and public health and law enforcement agencies in the study state. More broadly, we hope this study will

serve as a model for similar profiles in other jurisdictions and that our results will provide the basis for more detailed comparisons with other states.

METHODS

Measures

This register-based study used the California Department of Public Health's Multiple Cause of Death Data Files (MCOD) to identify all firearm-related fatalities in the state of California that occurred between January 1, 2000 and December 31, 2015. Firearm deaths were classified according to the 10th revision of the International Statistical Classification of Disease and Related Health Problems, and were determined to be homicides (U01.4, X93-95), suicides (X72-74), legal interventions (Y35.0), or of unintentional (X72-74) or undetermined (Y22-24) intent. The MCOD files included the decedents' sex, race/ethnicity, age, and county of residence. Age-adjusted rates were standardized to the age distribution of the US population in 2000 using direct standardization.

Statistical analysis

We described rates and counts over time and by age, stratifying by intent (i.e., homicide or suicide), gender, and race/ethnicity. Race/ethnicity was classified as non-Hispanic white (hereafter, "white"), non-Hispanic black (hereafter, "black"), Hispanic, Asian, or Native American. All rates were age-adjusted except for those that were evaluated by age group. To ensure subject anonymity, figures do not show results from strata with fewer than 15 deaths; rates and counts were pooled across years in subgroups with low counts, as needed, to minimize the number of suppressed data points.

We mapped county-level rates in order to describe the spatial distribution of firearm homicide and suicide in California. To address the inherent imprecision of small area statistics, county-level mortality rates were estimated using empirical Bayes methods obtained from random-intercept Poisson models.[6,7] Empirical Bayes predictions were generated by combining prior information regarding firearm mortality – in our case, the count of firearm deaths within each county – with a Poisson likelihood function. The extra Poisson variability was modeled by introducing county-specific random intercepts. The marginal distribution of the observed number of firearm deaths within counties was then used to generate the smoothed mortality rates by using the logarithm of the population as an offset in the model. With this method, the county-specific rates were predicted using information from other counties in order to shrink the estimates toward the overall rate.

We used these smoothed estimates to map the geographic distribution of firearm mortality rates by county over time. The smoothed crude rates for 2015 are displayed in cross-sectional maps, with counties divided into quintiles based on these rates. Additional maps show the county-specific average annual change in homicide and suicide rates from the state inflection point (2005 for homicide and 2006 for suicide) to 2015. To describe the urban-rural distribution of firearm mortality, we used the county-level metropolitan/nonmetropolitan classification from the United States Department of Agriculture's 2013 Rural-Urban Continuum Codes, which defines nonmetropolitan (rural) counties as having communities of fewer than 50,000 people with less than 25% of the workforce commuting to a metropolitan (urban) county.[8] These county classifications were included as independent variables in negative binomial models predicting

the number of firearm deaths within counties over time, which were used to summarize the spatial patterns of firearm mortality.

Final analyses were performed using R 3.4.2, Stata/MP 14.2, and GeoDa 1.8. This study was approved by the UC Davis Institutional Review Board.

RESULTS

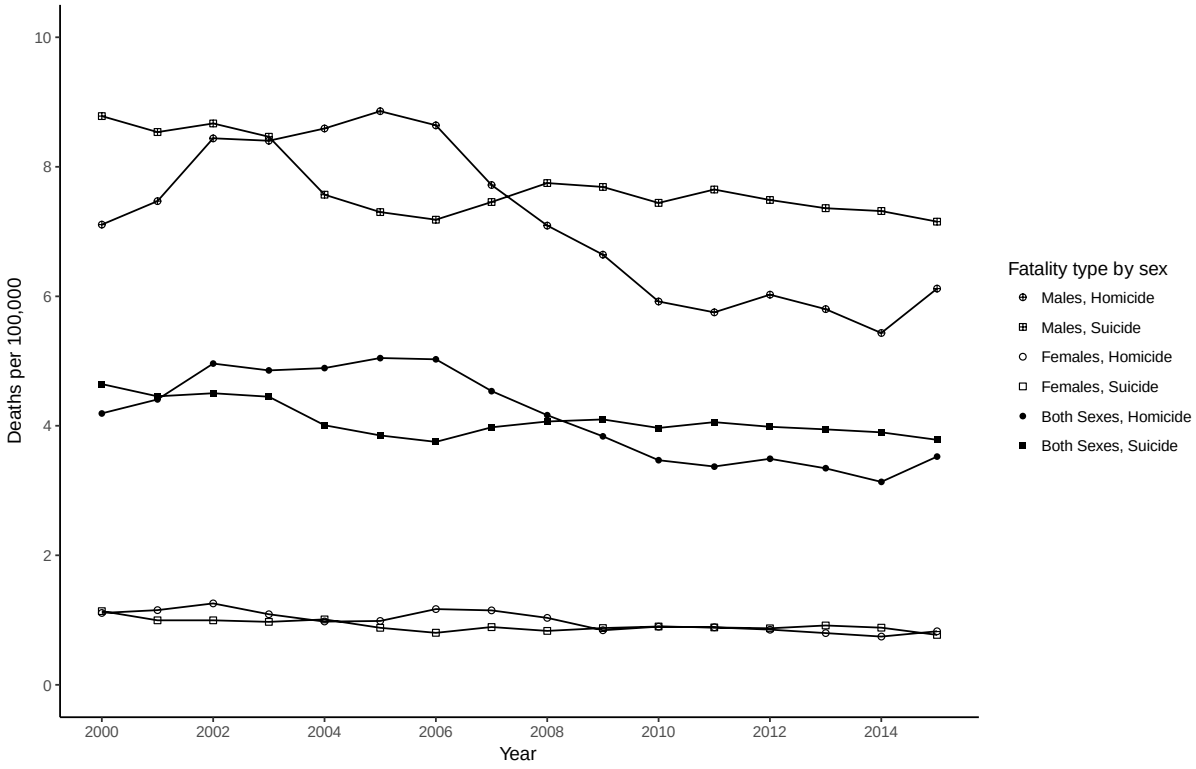
Over the 16 years from 2000 to 2015, there were 50,921 firearm-related deaths in California; 48.9% were homicides, 46.5% were suicides, 2.5% were from legal intervention, 1.6% were unintentional, and 0.5% were of undetermined intent. Since the vast majority (95.4%) of firearm deaths were homicides or suicides, we did not evaluate other intents individually.

Temporal trends

While homicide and suicide accounted for similar proportions of firearm deaths over the study period, their trends over time were markedly different (Figure 1). The statewide rate of firearm homicide increased from 4.19 per 100,000 in 2000 to a peak of 5.05 per 100,000 in 2005; since then, it declined to a low of 3.13 in 2014, but increased slightly in 2015. Conversely, the rate of firearm suicide decreased from 4.64 per 100,000 in 2000 to a low of 3.75 per 100,000 in 2006, thereafter plateauing around 4 deaths per 100,000.

Overall, the firearm homicide rate among men was 7.2 times the rate for women. These rates for men, stratified by race/ethnicity, are in Figure 2a. The absolute rise and fall in homicide was most substantial for black men, whose rate peaked in 2005 at 47.16 deaths per 100,000, and fell

Figure 1: Firearm mortality rates in California, 2000-2015

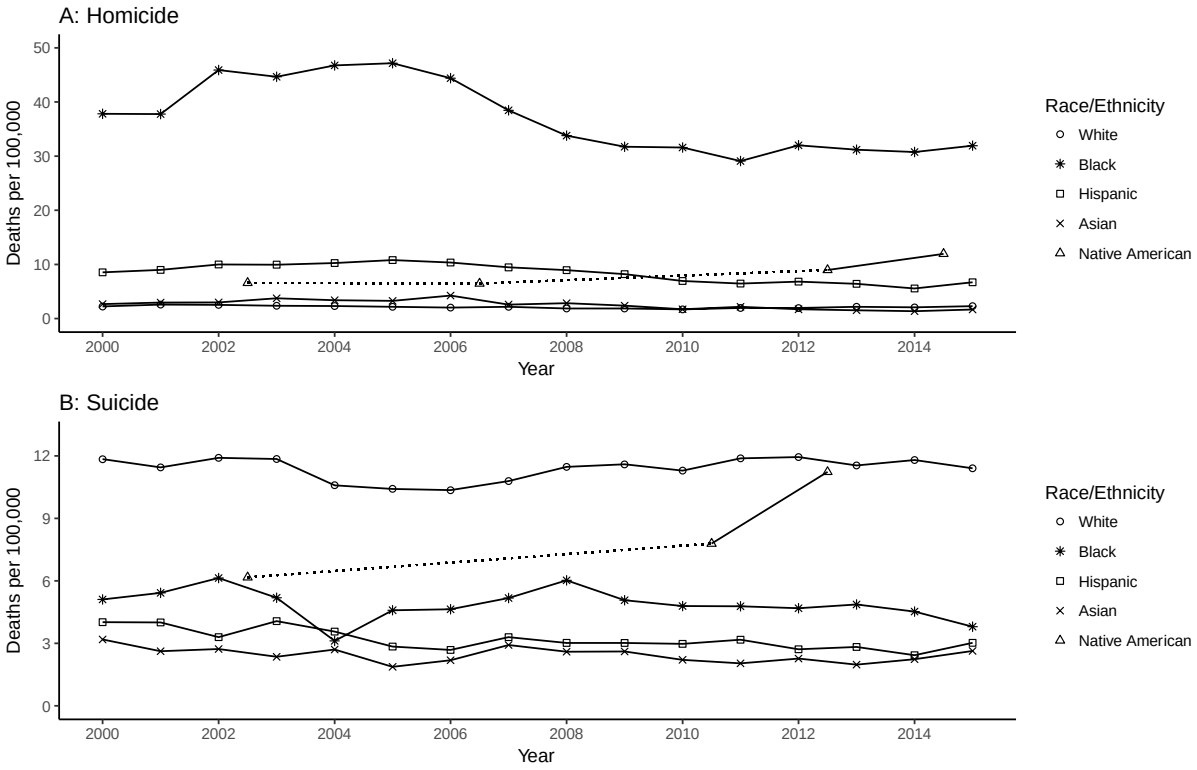


32% to 31.93 deaths per 100,000 by 2015. The firearm homicide rate for black men in their 20s approached 90 per 100,000 (Supplemental Figure 2a), driving the excess firearm mortality for black men as a whole. On average, the homicide rate for black men was 4.5 times the rate for Hispanic men, the group at next highest-risk. The rate for Hispanic men also peaked in 2005 and declined considerably (38%) to 6.71 per 100,000 by 2015. Native American men were the only racial/ethnic group with a notable increase (81%) in homicide rates; however, these rates are unstable due to small counts.

Among women, firearm homicide rates were also highest for blacks (Supplemental Figure 1a). The rate for black women peaked in 2006 at 5.25 deaths per 100,000 and trended downward thereafter; there is a good deal of year-to-year variation, however, due to small counts. On

average, rates among women of other races/ethnicities were less than 1 death per 100,000 and remained fairly steady.

*Figure 2: Firearm mortality rates among men in California, 2000-2015**



* Cells with <15 deaths were suppressed and not represented in the graph. A dotted line indicates interpolation over suppressed data. Rates for Native Americans were pooled over 2-year periods.

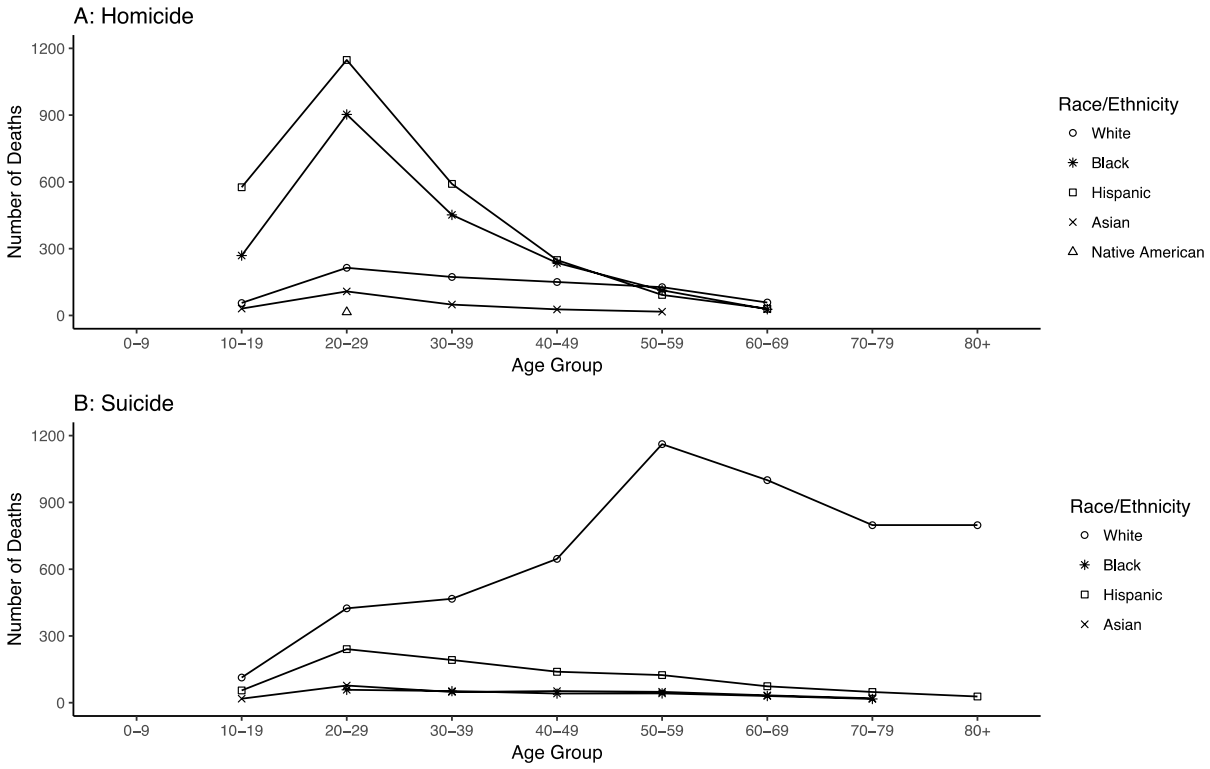
The firearm suicide rate among men was 8.5 times the rate for women, on average. Figure 2b shows race/ethnicity-specific rates of firearm suicide among men. Among white men, the rate of firearm suicide increased 10% following a nadir at 10.35 deaths per 100,000 in 2006. The rate for white men increased with age; at age 80 and above, white men had a rate more than 5 times that of the group at next highest-risk (Supplemental Figure 2c). The rate among Native American men also increased over the study period, though trends are difficult to confirm due to small cells.

Rates of firearm suicide for women are displayed Supplemental Figure 1b. White women consistently had the highest rate compared to other racial/ethnic groups, peaking at 1.75 deaths per 100,000 in 2013 but remaining fairly steady over the entire study period. The firearm suicide rate for other racial/ethnic groups also remained steady and low, rarely exceeding 0.5 deaths per 100,000.

Number of deaths

Figure 3a displays the number of firearm homicides aggregated over 2011-2015 by age, stratified by race and gender. Hispanic men between the ages of 20 and 29 suffered the greatest number of deaths (1,148), followed by black men of the same age (903 deaths). Young Hispanic and black

*Figure 3: Total firearm deaths among men in California by age (2011-2015)**

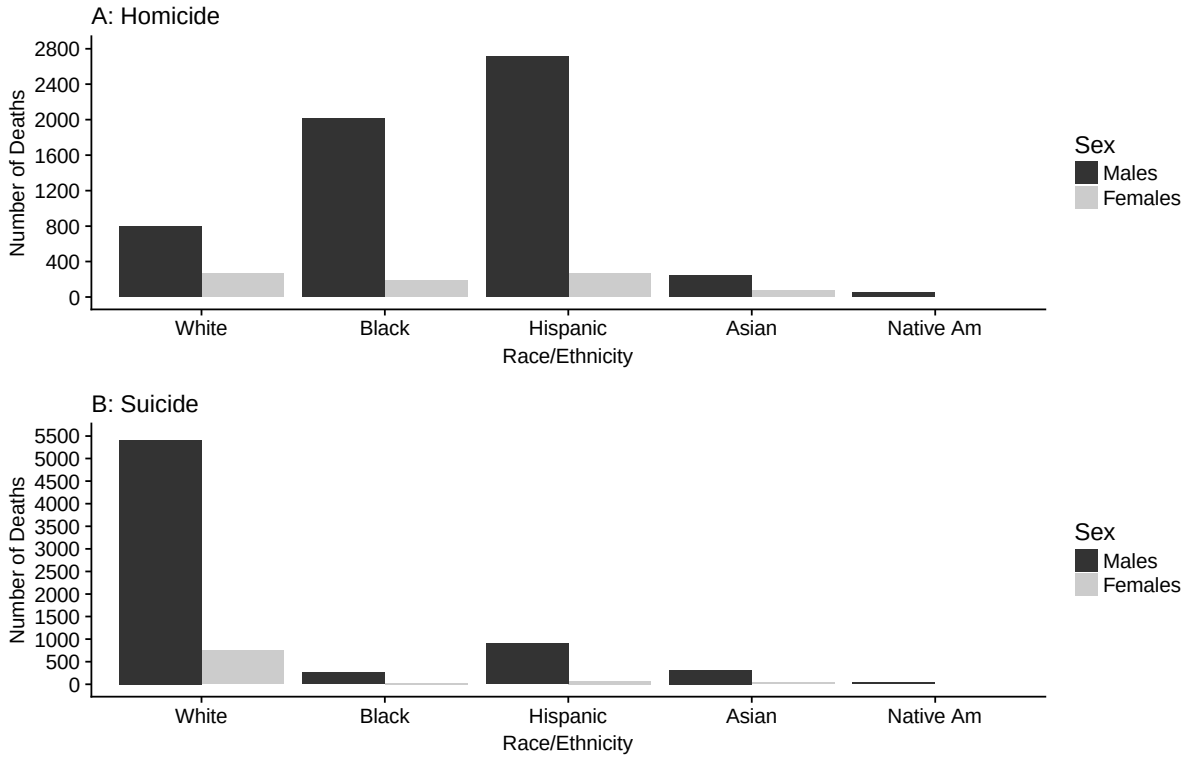


***** Cells with <15 deaths were suppressed and not represented in the graph. Missing race/ethnicity indicates that all data points were suppressed.

women follow the same pattern (Supplemental Figure 3a). From middle-age onward, however, whites had the greatest number of firearm homicides among women.

Figure 3b displays comparable results for suicide. White men had the highest number of firearm suicides across all ages, peaking in their 50s with 1,162 deaths. Suicides for non-white men follow a different trajectory, with the most deaths occurring between the ages of 20 and 29. Over the age of 80, white men had nearly 30 times the number of firearm suicides than Hispanic men, the only other racial/ethnic group with counts large enough to report.

*Figure 4: Total firearm deaths in California (2011-2015)**



* Native American women had <15 deaths for both outcomes, so their data were suppressed and are not represented in the graphs.

Among women, whites suffered the vast majority of firearm suicides, also peaking in their 50s (Supplemental Figure 3b). Among people aged 50 and older, white women had more deaths from firearm suicide than any group other than white men. For men and women together, whites had more than 6 times the number of deaths due to firearm suicide than any other racial/ethnic group (Figure 4b).

Geographical distribution

Figure 5a illustrates the geographical distribution of firearm homicide in 2015. Smoothed rates ranged from 1.05 to 10.40 deaths per 100,000, and tended to be higher in the San Joaquin Valley (an inland valley lying between Sacramento and Los Angeles [LA] counties). There was no significant difference in firearm homicide rates by county urban-rural status in 2015 (relative risk (RR) for nonmetropolitan counties: 0.85; 95% confidence interval (CI): 0.47, 1.52).

Figure 5: Smoothed firearm mortality rate quintiles by county in California, 2015

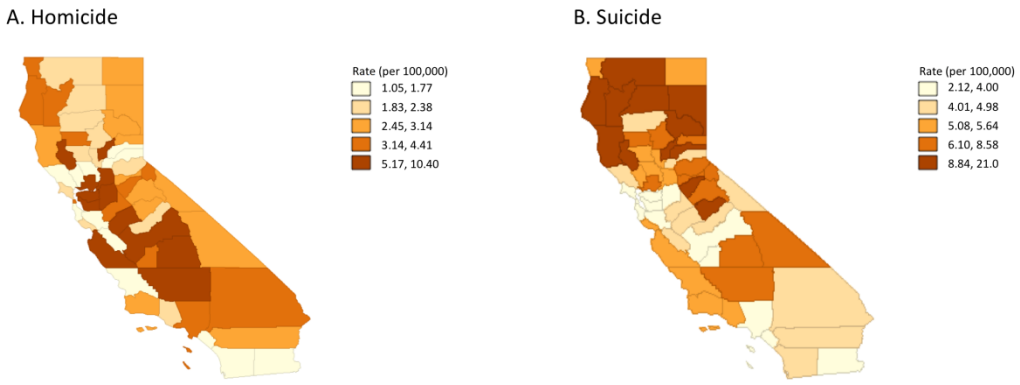
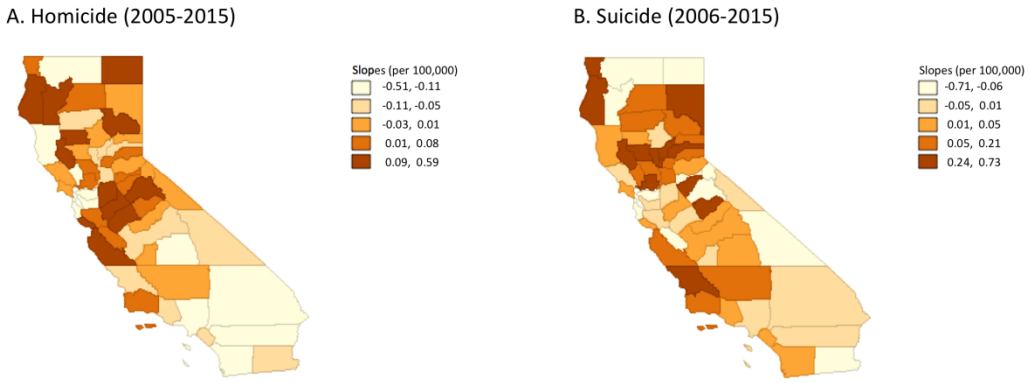


Figure 6a shows the yearly change in rates of firearm homicide by county from 2005 (the state's inflection point) to 2015; the rate decreased in 31 counties and increased in 27. The counties with

increasing rates of firearm homicide were scattered across Northern and Central California, while the counties with a net decrease were clustered in Southern California. Overall, nonmetropolitan counties had greater increases in firearm homicide rates than metropolitan counties had (RR: 1.08 95% CI: 1.01, 1.16). The five most populous counties in the state (Los Angeles, San Diego, Orange, Riverside, and San Bernardino) all had net decreases.

Figure 6: Average annual change in firearm mortality rate by county in California



LA County, home to more than one-quarter of the state's population, experienced a 54% decline in firearm homicides from its peak rate in 2002. Absent LA County, California would have had an increase of 0.51 firearm homicides per 100,000 from 2000 to 2015; with it, the overall change was negative (-0.81 deaths per 100,000). There was a sharp decline in firearm homicide rates among black men, dropping from 61.11 to 38.76 deaths per 100,000 over the study period. However, the decline in LA County was primarily due to the reduction in firearm homicides among Hispanic men, who make up nearly 25% of the county's population[9] and whose age-adjusted rate decreased by 52% from 14.23 to 6.82 deaths per 100,000.

Firearm suicide rates varied widely by county, ranging from 2.12 to 21.03 deaths per 100,000 residents in 2015. They were about 3 times higher in nonmetropolitan counties than in metropolitan counties (RR: 3.06; 95% CI: 2.28, 4.12). These nonmetropolitan counties were clustered in Northern California; suicide rates were lowest in the Bay Area and LA County (Figure 5b).

Since the statewide low in firearm suicide in 2006, 38 counties have experienced average increases in firearm suicide rates, and 20 have had decreases (Figure 6b). The average yearly change in the rate of firearm suicide ranged from -0.71 to 0.73 deaths per 100,000. The 38 counties with net increases do not follow a discernible geographic pattern, nor do they seem to vary by metropolitan and nonmetropolitan counties (RR: 1.01; 95% CI: 0.99, 1.03).

DISCUSSION

Firearm mortality in California over our 16-year study period exhibited important variation in homicide and suicide. Since 2005, firearm homicide has declined substantially, driven by reductions in Los Angeles County. Firearm suicide, however, has increased slightly since the mid-2000s. Black men had the highest firearm homicide rate, but the number of deaths from firearm homicide was highest among Hispanic men. White men had the highest rate and number of deaths from firearm suicide. Firearm homicide rates declined more in urban rather than in rural counties, such that by the end of the study period there was no significant difference in rates between urban and rural areas. Firearm suicide rates did not change differentially by county urban-rural status, but did show significant clustering in rural areas in 2015.

Trends in firearm homicide and suicide in California were similar to national trends over the study period, though California's decline in homicide has been sharper and its increase in suicide has been more modest. Consistent with our findings for California, a national study found that firearm homicides have been declining and suicides have been increasing since around 2006.[10] It is unclear what precipitated these changing trends, but just as we saw with LA County, the national decline in firearm homicides seems to be in large part driven by falling rates in major urban areas.[11] The trends appear be changing, however, as homicide rates in some metropolitan areas across the US increased sharply in recent years.[12]

Major gender- and race-specific trends of firearm mortality in California conform to the findings in national studies, which show that the rate of firearm violence is much higher in men, particularly young black men (for homicide) and older white men (for suicide).[10,13] Native American men consistently had the second-highest rate of firearm suicide nationally,[1,13] and in California, the rate approached that of white men around 2013. As most of the yearly rates for Native Americans were based on small counts, the data do not allow us to draw any firm conclusions. Nevertheless, the sharp increase in firearm suicide among this group should be investigated further.

California diverged from the nation with regard to the racial distribution of the number of firearm homicides. Nationally, the absolute burden of firearm homicides was highest among blacks, who account for about 57% of these deaths,[1] but in California, the number of firearm homicides was highest among Hispanics (45%). This is certainly due, in part, to the unique demography of California, which was 36% Hispanic over the study period. This serves as an

important reminder that rates and counts provide complementary information, and that both are necessary to fully understand how a condition is distributed throughout a population.

California and the US also differ in the relative frequencies of firearm homicide and suicide. Nationally, suicides made up over 60% of all deaths from firearm violence between 2000 and 2015, and homicide rates never exceeded suicide rates during this period.[1] In California, firearm homicide accounted for 51% of deaths from firearm violence and exceeded firearm suicide from 2001 to 2008. One reason for this predominance of homicides in the first part of our study period could be that California has several large cities, which are historically where homicide rates have been highest.

Our findings with regard to the urban-rural distribution of firearm homicide were also surprising given historical patterns. Consistent with existent literature, we found firearm homicide to be largely an urban problem at the start of the study period;[14] however, falling rates in urban counties resulted in more rural areas in the central part of the state having the highest rates of firearm homicide by 2015. The major decline in firearm homicide in the most populous counties is likely driven by a reduction in gang violence, particularly among Hispanic men;[15,16] however, it is unclear why gang violence declined over this period.

The urban-rural distribution of firearm suicide in California is consistent with a national county-level analysis of firearm mortality, which also found that there were higher rates of firearm suicide in rural counties.[14] Greater prevalence of firearms and limited access to mental health

care likely accounts for some of the excess firearm suicides in these areas,[17] but more research is needed to uncover other factors that contribute to the urban-rural distribution of firearm suicide.

Our profile of the epidemiology of firearm morality in California can inform targeted interventions and resource allocation. This within-state study found that firearm homicide is likely felt most acutely in black communities due to the very high rate among young black men, but that Hispanics may need more resources, as they suffer the plurality of deaths. This study also revealed counties that have made great strides in reducing firearm mortality and those that need more work, which can inform local firearm policy across the state. Within-state studies can also generate important research questions. For example, what happened in Los Angeles County that led to the massive decline in firearm homicides, and can it be replicated in other areas? Why do Hispanics account for such a large percentage of homicides but a relatively small percentage of suicides? The findings presented here do not generalize beyond California, but similar within-state studies would provide other states with state-specific, policy-relevant insights like those presented here.

Limitations

This study's findings should be considered in light of several limitations. Due to small numbers, we were required to suppressed rates for some subgroups of interest, limiting our ability to present patterns of mortality for Native Americans, Asian women, and black women. Additionally, we restricted our study to firearm homicide and suicide, due to the small number of firearm deaths from other causes, and our data did not include nonfatal injuries, thus presenting a restricted view of the epidemiologic profile of firearm violence in California.

CONCLUSIONS

Firearm violence is a substantial public health problem that results in premature death and confers enormous health, economic, and social costs to the United States. Our study provided an in-depth look into the epidemiology of firearm violence in California over 16 years with results that are likely to inform policy, practice, and future research. Similar studies in other states should yield similar benefits.

ACKNOWLEDGEMENTS

We would like to thank Prof. George Tita and Christopher McCort for their contributions.

Funding: Funding for this project was provided by the Heising-Simons Foundation (grant #2016-219) and by the State of California through the University of California Firearm Violence Research Center. RMCK and ACC were supported in part by the Robertson Fellowship in Violence Prevention Research. ACC was also supported by Becas Chile as part of the National Commission for Scientific and Technological Research (CONICYT).

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Figure legends:

1. Firearm mortality rates in California, 2000-2015
2. Firearm mortality rates among men in California, 2000-2015*
    a. * Footnotes: Cells with <15 deaths were suppressed and not represented in the graph. A dotted line indicates interpolation over suppressed data. Rates for Native Americans were pooled over 2-year periods.
3. Total firearm deaths among men in California by age (2011-2015)*
    a. *Footnotes: Cells with <15 deaths were suppressed and not represented in the graph. Missing race/ethnicity indicates that all data points were suppressed.
4. Total firearm deaths in California (2011-2015)*
    a. *Footnotes: Native American women had <15 deaths for both outcomes, so their data were suppressed and are not represented in the graphs.
5. Smoothed firearm mortality rate quintiles by county in California, 2015
6. Average annual change in firearm mortality rate by county in California

Conflict of Interest and Authorship Conformation Form

Please check the following as appropriate:

- ✓ All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.
- ✓ This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue.
- ✓ The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript
- o The following authors have affiliations with organizations with direct or indirect financial interest in the subject matter discussed in the manuscript:

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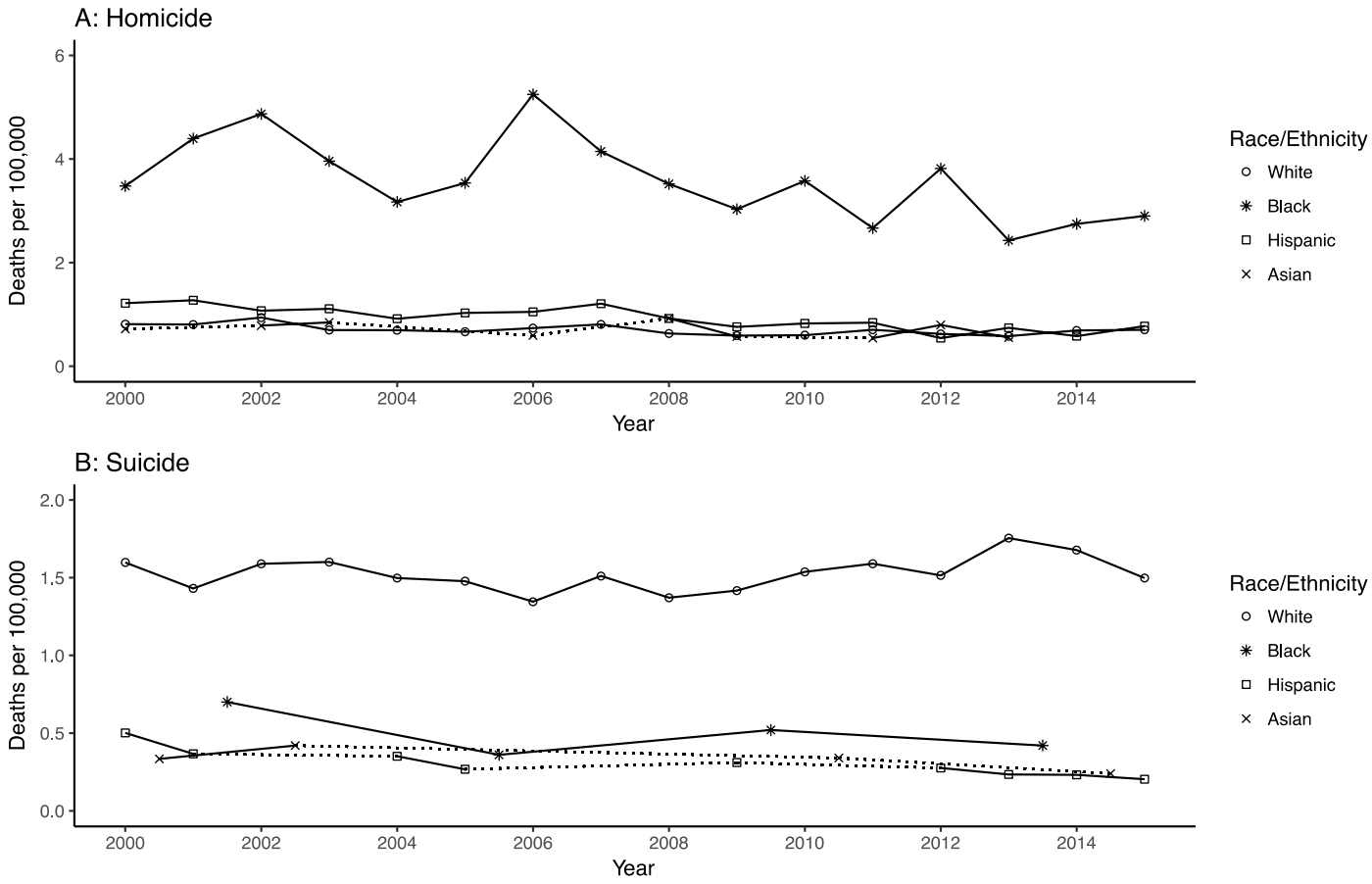
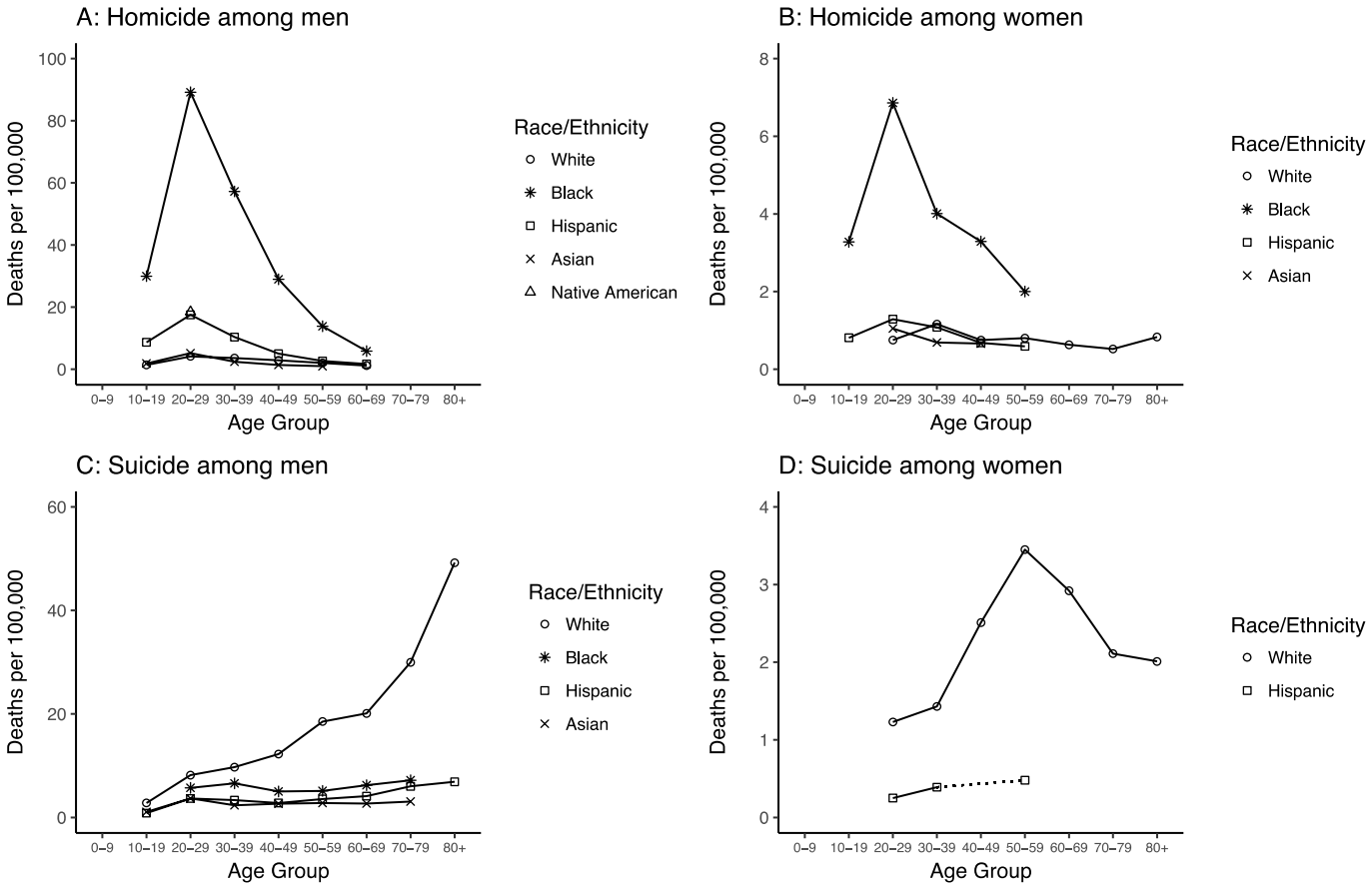
Supplemental Figure 1: Firearm mortality rates among women in California, 2000-2015*



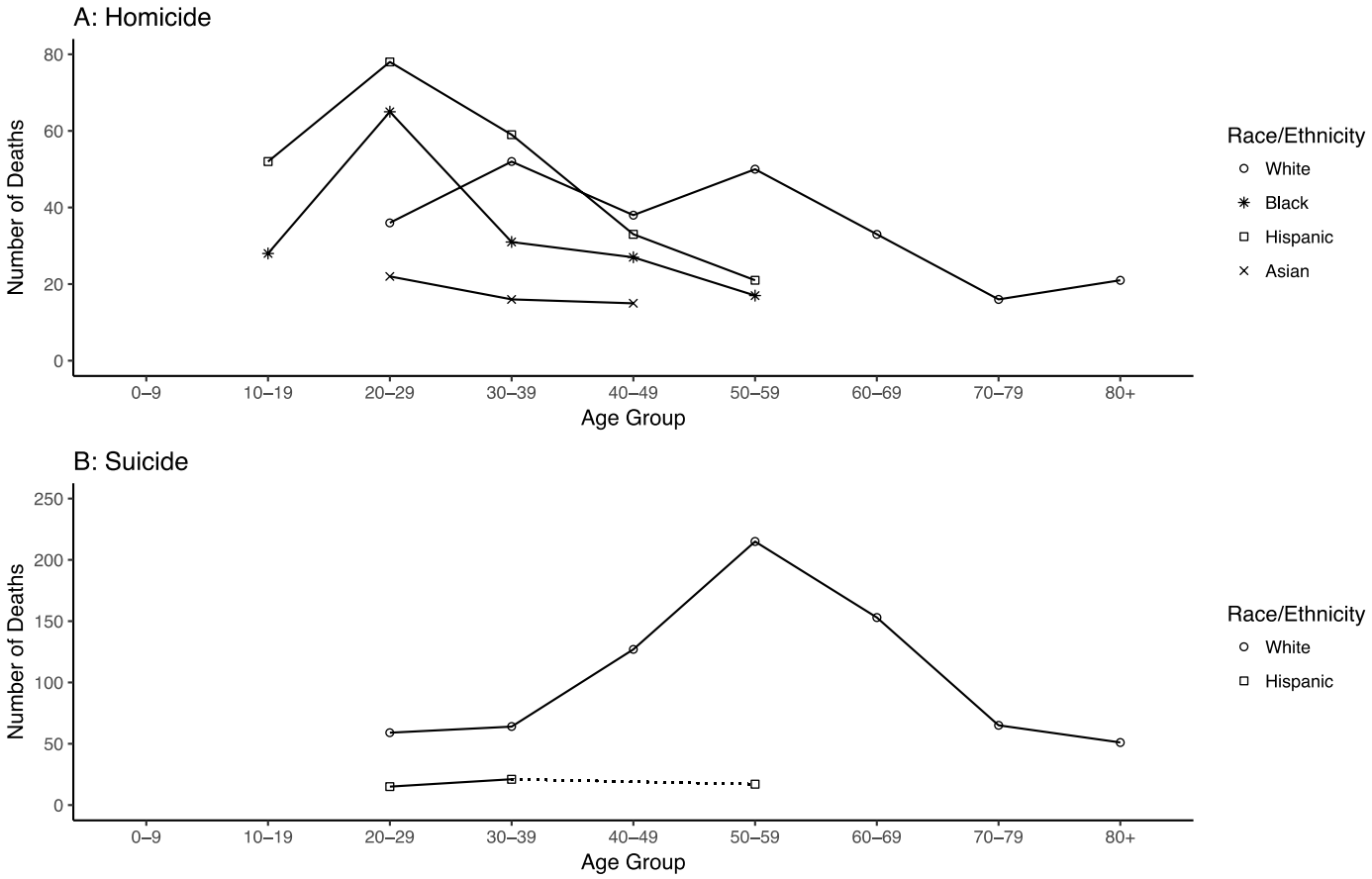
* Cells with <15 deaths were suppressed and not represented in the graph. Missing race/ethnicity indicates that all data points were suppressed. A dotted line indicates interpolation over suppressed data. Rates for Native American women were pooled over 4-year periods. Suicide rates for black women were pooled over 4-year periods, and suicide rates for Asian women were pooled over 2-year periods.

Supplemental Figure 2: California firearm mortality rates by age (2011-2015)*



*Cells with <15 deaths were suppressed and not represented in the graph. Missing race/ethnicity indicates that all data points were suppressed. A dotted line indicates interpolation over suppressed data.

Supplemental Figure 3: Total firearm deaths among women in California by age (2011-2015)*



*Cells with <15 deaths were not represented in the graph. Missing race/ethnicity indicates that all data points were suppressed. Dotted line indicates interpolation over suppressed data.