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Research Paper

Association of state-level factors with rate of firearm-related deaths☆,☆☆

Emily A. Grimsley, MD *, Meagan D. Read, MD, Michelle Y. McGee, MD, Johnathan V. Torikashvili, BS, Noah T. Richmond, BS, Haroon M. Janjua, MS, Paul C. Kuo, MD, MS, MBA

Department of Surgery, University of South Florida Morsani College of Medicine, Tampa, FL, United States of America

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ABSTRACT

Background: Over 48,000 people died by firearm in the United States in 2021. Firearm violence has many inciting factors, but the full breadth of associations has not been characterized. We explored several state-level factors including factors not previously studied or insufficiently studied, to determine their association with state firearm-related death rates.

Methods: Several state-level factors, including firearm open carry (OC) and concealed carry (CC) laws, state rank, partisan lean, urbanization, poverty rate, anger index, and proportion of college-educated adults, were assessed for association with total firearm-related death rates (TFDR). Secondary outcomes were firearm homicide (FHR) and firearm suicide rates (FSR). Exploratory data analysis with correlation plots and ANOVA was performed. Univariable and multivariable linear regression on the rate of firearm-related deaths was also performed.

Results: All 50 states were included. TFDR and FSR were higher in permitless OC and permitless CC states. FHR did not differ based on OC or CC category. Open carry and CC were eliminated in all three regression models due to a lack of significance. Significant factors for each model were: 1) TFDR – partisan lean, urbanization, poverty rate, and state ranking; 2) FHR – poverty rate; 3) FSR – partisan lean and urbanization.

Conclusions: Neither open nor concealed carry is associated with firearm-related death rates when socioeconomic factors are concurrently considered. Factors associated with firearm homicide and suicide differ and will likely require separate interventions to reduce firearm-related deaths.

Key message: Neither open carry nor concealed carry law are associated with total firearm-related death rate, but poverty rate, urbanization, partisan lean, and state ranking are associated. When analyzing firearm homicide and suicide rates separately, poverty rate is strongly associated with firearm homicide rate, while urbanization and partisan lean are associated with firearm suicide rate.

Introduction

Firearm violence rates continue to rise in the United States (US). Over 48,000 people died by firearm in 2021, equating to 14.6 deaths per capita [1]. Firearm injuries and subsequent deaths significantly impact our healthcare system and communities. As surgeons, we are not strangers to firearm injuries and have unfortunately seen an increasing number of firearm injury hospitalizations in the past three years [2–4].

There is a plethora of literature about factors associated with firearm-related violence, and the evidence is clear that numerous factors are at play, including firearm laws and socioeconomic factors. Several studies have found associations between specific firearm laws and firearm-related deaths [5–14], but no recent studies have examined the impact of open carry (OC) laws. Additionally, numerous studies have examined concealed carry (CC) laws and firearm-related death rates, but the results have been mixed [6,9,11,15]. This may be due to the way each study categorized concealed carry law. For example, one study reported whether or not a state had discretion when issuing a concealed carry permit (so-called "may-issue") [7], while another combined "may-issue" and "no-issue" (i.e. - concealed carry not legal) into the same

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* Corresponding author.
E-mail address: grimsley@usf.edu (E.A. Grimsley).
@egrimsleymd (E.A. Grimsley)

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category [6]. In addition to these studies having mixed results, we must also mention that there are no longer any "no-issue" states; as of 2014 all states allow concealed carry either with or without a permit. Changes in legislation and the variety in which concealed carry has been characterized in previous literature warrant additional study.

Social and economic factors such as poverty rate [16,17] and education level [18] have been directly associated with firearm-related deaths, though in few studies. Several additional factors have not been directly assessed for association with firearm-related death rates, but have been adjacently studied. These include partisanship [19] and urbanization [20]. The extent of socioeconomic factors associated with firearm-related deaths remains understudied.

The underlying motivation for this study is to characterize factors that contribute to increased gun deaths in the US, drawing on a myriad of potential factors that have been hitherto assumed to play a role. In this study, we examined understudied and not previously studied firearm laws, social, and economic factors for association with firearm-related deaths.

Methods

Study design

We performed a cross-sectional study to examine associations between different exposures and the primary outcome of interest, total firearm-related death rate per state. Secondary outcomes were firearm homicide and firearm suicide rates. Exposures included OC and CC laws, and socioeconomic factors (poverty rate, college education rate, partisan lean, urbanization, anger index, and overall ranking) per state. This study was exempt from the Institutional Review Board due to utilizing solely aggregate, state-level data.

Firearm legislation

First, we reviewed state laws for legislation regarding OC and CC for handguns as of 2021. We examined handgun laws as the majority of firearm homicides and suicides in this country are with handguns [21,22]. For OC, states fell into one of three categories: 1) non-open carry (NOC; open carry of loaded handgun is illegal); 2) open carry with permit (POC; additional permit or license required to openly carry a loaded handgun); or 3) permitless open carry (PLOC; no additional permit or license required to openly carry a loaded handgun). For CC, states were classified as: 1) may-issue (MCC; more restrictive law that gives issuing agency discretion to deny a concealed carry permit to an applicant), 2) shall-issue (SCC; issuing agency is required to issue concealed carry permit to applicants that meet the requirements set forth by state law/less restrictive), 3) permitless concealed carry (PLCC; no additional permit or license required to concealed carry a loaded handgun).

Socioeconomic variables

The aforementioned included socioeconomic variables were chosen based on their demonstrated relationship with either violent crime or firearm legislation [13,16–20]. Two novel variables, state ranking and anger index, were included to assess for possible novel, significant associations with the firearm-related death rate. State rankings were based on the 2021 U.S. News and World Report rankings that take into account healthcare, education, economy, infrastructure, public safety, and fiscal stability of the state government in order to determine the rank of the 50 contiguous United States. Healthcare and education are most heavily weighted as based on a survey of what people reported mattered most to them in a state [23]. The anger level of each state was determined by the 2021 Anger Index. This was created from a weighted algorithm of the following three variables: 1) National Highway Traffic Safety Administration's Fatality Analysis reporting system (how many road rage fatalities per capita in each state), 2) Wired Magazine's data about online angry/toxic comments in each state, and 3) the Federal Bureau of Investigation's hate crimes data [24].

Partisan inclination, herein referred to as 'partisan lean,' per state was taken from a 2020 report that averaged the difference between how the state votes and how the country votes overall. The scoring was based on 2020 presidential election results (50% influence), 2016 presidential election results (25% influence), and state legislature votes (25% influence). A more positive number was defined as a more Democratic-leaning state than national average, while a more negative number was defined as a more Republican-leaning state than national average [25].

Urbanization of a state was calculated by taking the average number of people living within a five-mile radius of every census tract, and used the natural log to create an 'urbanization index.' The higher the number, the more urban the state [26]. Poverty levels were based on United States Department of Agriculture data from 2020, reporting the percent of people below the poverty line in every state [27]. The fraction of college educated adults per state was gathered from the Economic Research Federal Reserve Bank of St. Louis [28].

Outcomes

The primary outcome was total firearm-related deaths per 100,000 people per state (herein referred to as total firearm-related death rate; TFDR). Secondary outcomes were specifically firearm homicide rate (FHR) and firearm suicide rate (FSR), which were analyzed separately as previous literature has found different factors associated with each. We utilized the 2021 Center for Disease Control (CDC) Web-based Injury Statistics Query and Reporting System data for all three outcomes [1]. As the CDC does mask homicide numbers <10 per year in a given state, for Vermont and New Hampshire, we found firearm homicide counts for 2021 via the Federal Bureau of Investigation's Crime Data Explorer [22].

Statistical analysis

First, we normalized all numeric variables (all outcomes and exposures, except for the categorical firearm law variables) using a standard Z-score approach. Next, we performed exploratory data analysis using correlation plots to assess the correlation between each numeric exposure and the outcomes. Comparison of TFDR, FHR, and FSR by firearm law category was performed using ANOVA with post-hoc Tukey's test.

Finally, we performed univariable and multivariable linear regressions. Separate regressions were performed for the three outcome variables (TFDR, FHR, and FSR). Covariates were all exposures. For each regression, the full model included all exposures. We then excluded exposures that were multicollinear, defined as a variance inflation factor > 5 [29]. We reran the model and then excluded any variable with highly insignificant p values (defined as $p > 0.2$). Our final models were the result of these exclusions. As the variables are Z-score normalized, the final models display a standardized beta coefficient, displayed in units of standard deviation, for each independent variable. Since all variables are on the same scale, a standardized beta coefficient allows us to compare the strength of the effect of each individual independent variable within a multivariable model. Stronger effects will have higher absolute values, while positive vs. negative will indicate the direction of relationship [30]. For all analyses, p values < 0.05 were considered significant. We used StataSE 17 [31] for data pre-processing and ANOVA, and R Studio [32] for Z score, generating correlation plots, and regression.

Results

We included all 50 states. Supplemental Table 1 shows raw data by state. Total firearm-related death rate ranged from 3.4 to 33.9 deaths per capita (median 16.2, interquartile range [IQR] 11.9–21.1). Firearm

homicide rate ranged from 0.65 to 19.76 deaths per capita (median 4.93, IQR 2.72–8.06). Firearm suicide rate ranged from 1.95 to 23.67 deaths per capita (median 10.27, IQR 7.69–12.11).

Correlation plots for numeric exposures and outcomes are in Fig. 1. Key findings include a moderate positive correlation between TFDR and poverty rate, and a moderate negative correlation between TFDR and the proportion of college-educated adults. For FHR, there was a strong positive correlation to the poverty rate and a moderate negative correlation with state ranking. Unlike TFDR and FHR, for FSR, there was no significant correlation with poverty rate. There was, however, a strong negative correlation to urbanization (meaning the more urban the state, the lower the suicide rate) and a moderate (almost strong) negative correlation to partisan lean (meaning the more Republican a state, the higher the suicide rate). Notably, the anger index did not significantly correlate with any of the three outcomes.

For OC law, five states were NOC, 10 were POC, and 35 were PLOC. Total firearm-related death rate and FSR were significantly higher in PLOC states than in NOC and POC states (all $p < 0.01$), but did not differ between NOC and POC. There was no significant difference in FHR based on the OC category (Table 1). For CC law, eight states were MCC, 22 were SCC, and 20 were PLCC. Total firearm-related death rates were significantly higher in SCC and PLCC states, compared with MCC states (all $p < 0.01$), but did not differ between SCC and PLCC states. There was a significant difference between all three CC categories for FSR, with MCC states having the lowest rate and PLCC states having the highest rate (all $p < 0.01$). For FHR, there were no significant differences based on CC category (Table 2).

Table 3 shows univariable and multivariable linear regression results for each outcome. Due to a lack of significance, both OC and CC were eliminated from the models for all three outcomes. For TFDR, the final model included partisan lean (multivariable beta coefficient [B] -0.27), urbanization (B -0.26), poverty rate (B 0.33), and state ranking (B -0.28), with all factors significant in univariable and multivariable analysis (multivariable model $R^2 = 0.72$). For FHR, the final model included urbanization and poverty rate, though only the poverty rate (B 0.8) was significant in univariable and multivariable regression (multivariable model $R^2 = 0.62$). For FSR, the final model included partisan lean, urbanization, poverty rate, and state ranking. Partisan lean (B -0.36) and urbanization (B -0.5) were significantly associated; poverty rate and state ranking were not significant in univariable or multivariable regression (multivariable model $R^2 = 0.61$). While poverty rate had the strongest association with TFDR and FHR, urbanization had the strongest association with FSR.

Table 1
Firearm-related death rates in relation to state open carry law.

	NOC (n = 5)	POC (n = 10)	PLOC (n = 35)	p-Value
TFDR	9.88 ± 5.08	11.68 ± 6.69	18.62 ± 5.87[a]	<0.01
FHR	5.25 ± 3.45	5.03 ± 3.86	6.66 ± 4.67	0.523
FSR	6.51 ± 4.20	6.25 ± 3.94	10.89 ± 4.06[a]	<0.01

Displayed as mean ± SD. NOC = no open carry. POC = permit-required open carry. PLOC = permitless open carry. TFDR = total firearm-related death rate. FHR = firearm homicide rate. FSR = firearm suicide rate.
[a] PLOC significantly higher than NOC and POC (all $p < 0.01$).

Table 2
Firearm-related death rates in relation to state concealed carry law.

	MCC (n = 8)	SCC (n = 22)	PLCC (n = 20)	p-Value
TFDR	8.15 ± 5.05[a]	16.74 ± 5.81	19.23 ± 6.03	<0.01
FHR	4.52 ± 3.37	7.34 ± 4.08	5.59 ± 4.93	0.22
FSR	4.84 ± 3.84	7.98 ± 2.49	13.10 ± 3.79	<0.01[b]

Displayed as mean ± SD. MCC = may-issue concealed carry permit. SCC = shall-issue concealed carry permit. PLCC = permitless concealed carry. TFDR = total firearm-related death rate. FHR = firearm homicide rate. FSR = firearm suicide rate.
[a] MCC significantly lower than SCC and PLCC (all $p < 0.01$).
[b] All three groups significantly different (all $p < 0.02$).

Discussion

This state-level cross-sectional study investigated the relationship between understudied firearm legislation, social, economic factors, and firearm-related death rates. Our study further highlights the complexity between state factors and firearm-related deaths. Notably, factors associated with firearm-related homicides and suicides differ, but

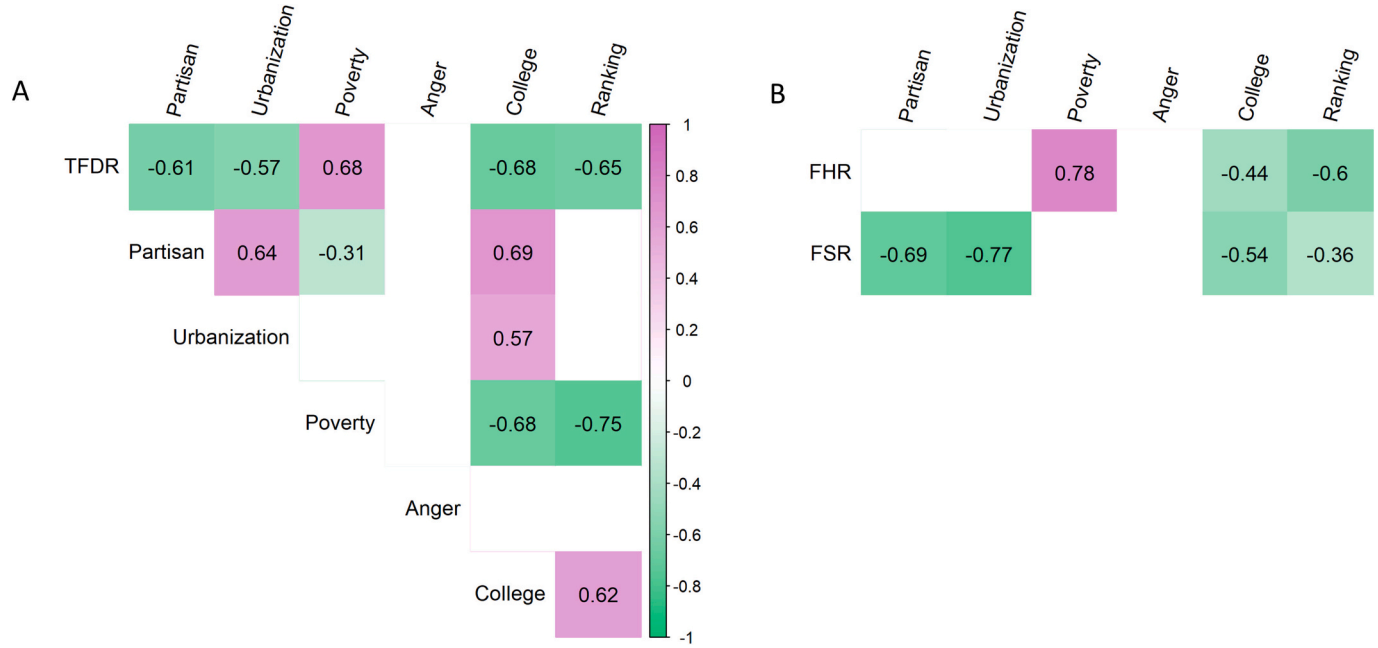

Fig. 1. Correlation plots between outcomes and exposures. A) Correlations between Total firearm-related death rate (TFDR) and all numeric exposures. B) Correlations between firearm homicide rate (FHR), firearm suicide rate (FSR), and all numeric exposures. Blank squares indicate non-significant relationships. All correlation values displayed carry $p < 0.05$.

Table 3
Univariable and multivariable linear regression final model results for each outcome.

	Univariable		Multivariable	
	B (95% CI)	p	B (95% CI)	p
TFDR				
Partisan lean	−0.61 (−0.84, −0.38)	<0.01	−0.27 (−0.48, −0.05)	0.02
Urbanization	−0.57 (−0.81, −0.33)	<0.01	−0.26 (−0.47, −0.05)	0.02
Poverty rate	0.68 (0.46, 0.89)	<0.01	0.33 (0.08, 0.57)	0.01
Ranking	−0.65 (−0.87, −0.43)	<0.01	−0.28 (−0.52, −0.04)	0.03
FHR				
Urbanization	−0.04 (−0.33, 0.25)	0.78	0.13 (−0.06, 0.32)	0.16
Poverty	0.78 (0.59, 0.96)	<0.01	0.8 (0.62, 0.99)	<0.01
FSR				
Partisan lean	−0.65 (−0.87, −0.43)	<0.01	−0.36 (0.61, −0.11)	<0.01
Urbanization	−0.72 (−0.92, −0.52)	<0.01	−0.5 (−0.75, −0.26)	<0.01
Poverty rate	0.12 (−0.17, 0.4)	0.42	−0.26 (−0.54, 0.03)	0.08
Ranking	−0.22 (−0.5, 0.07)	0.13	−0.2 (−0.49, 0.08)	0.15

B = standardized beta coefficient. 95% CI = 95% confidence interval. TFDR = total firearm-related death rate. FHR = firearm homicide rate. FSR = firearm suicide rate.

contribute to the factors associated with total firearm-related death rates. In multivariable analysis, neither open carry nor concealed carry law was significantly associated with death rates.

The factors contributing to TFDR stem from the factors contributing to FHR and FSR, which is logical. Our findings provide further evidence for the strong association between poverty levels and firearm deaths – of all the variables in our final regression models, poverty carried the highest regression coefficient for TFDR and FHR models, indicating the strongest effect on the outcome. This supports previous studies that have reported disproportionately higher firearm-related death rates in more impoverished counties [16,17]. Barrett et al. found that > 50% of all firearm-related deaths, and > 66% of firearm-related homicides, occur in the counties with the highest levels of poverty [16]. Another county-level study found that the most impoverished counties had not only the highest firearm homicide rates but also the highest firearm suicide rates [17]. It seems fair to infer that interventions to reduce our country's poverty rates may reduce firearm-related death rates.

State ranking was negatively associated with TFDR in our multivariable regression, and it remained in the final model for FSR, though it was not significant. While the rankings consider the violent crime rate, this makes up <2% of the index score. In comparison, the other 98% includes healthcare, education, economy, infrastructure, opportunity, fiscal stability of state government, and natural environment [23]. Given the richness of the overall variable, and the small proportion attributed to violent crime (of which only a proportion is firearm homicides as examined in our study), we felt state ranking was a valid variable to keep in the study. Since the ranking is a conglomerate variable, it would be worthwhile in future works to analyze each metric used to create the state ranking separately to see if more specific associations to firearm-related deaths can be elucidated.

The other two factors significantly associated with TFDR were partisan lean and urbanization. While the state's partisan lean was associated with firearm-related deaths, we acknowledge these values change with time and state-level lean does not always represent the largest proportion of the state population. We could not identify other studies comparing partisan lean with firearm-related deaths. However, a previous study did find states with stronger gun laws more often voted for the Democratic presidential candidate [19] and suggests there are likely complex relationships at play that influence firearm legislation and subsequent firearm violence. Further work will be needed to validate whether partisan lean is a novel association or an overarching marker of other state-level factors influencing firearm-related deaths. With a more granular study at the city or zip code level, it will be interesting to see if this association holds.

The relationship between urbanization and firearm deaths was established at the county level by Reeping et al., who found that the most rural counties in America had the highest total firearm death and firearm suicide rates and the lowest firearm homicide rates [20]. These findings mirror our results that showed the more rural the state, the higher the TFDR and FSR. There was additionally no association between urbanization and FHR in our multivariable analysis. Thus, we can conclude that more rural areas are at risk for higher firearm suicides, which drives total firearm-related deaths in these areas. One suggestion to mitigate this would be additional attention to mental health resources in rural areas, though further study would first be warranted.

An association between education level and firearm mortality has been established [18] and agrees with our univariable correlation analysis. In Fig. 1, our correlation plot shows a moderate negative association between college education and TFDR and FSR and a weak negative association with FHR. However, in multivariable linear regression, college education was found to be prohibitively multicollinear and thus was removed from the models. This does not mean college education was not associated with the outcome, but rather that it was highly correlated with other variables in the model. Indeed, college education was moderately associated with partisan lean, urbanization, poverty rate, and state ranking in our initial correlation analysis. This brings up an interesting point that the factors related to firearm deaths overlap and influence each other, making it difficult to determine causality.

Regarding firearm legislation explored in this study, we found that both OC and CC laws were not significantly associated with the outcomes in multivariable regression. Interestingly, permitless OC states had significantly higher TFDR and FSR (no difference between NOC and POC). While non-significance in the multivariable analysis may be due to the small sample size, other factors, rather than open carry legality, may lead to higher firearm-related death rates. To date, only three studies have assessed for association between open carry laws and firearm-related deaths, and none have found a significant association. Murray completed the first study in 1975 and found none of the studied gun laws (including open carry) were significantly associated with homicide or suicide rates as of 1970 [33]. In 1982, Lester & Murrell examined the cumulative effect of handgun carrying permit requirements (both open and concealed) and did not find a significant association with either firearm suicide or homicide [34]. Kleck et al. found no association between open carry legislation and firearm homicide rates [35]. Though they analyzed open and concealed carry together, their results concur with ours. The cumulative results would suggest that, when taking into account other significant associations such as socioeconomic factors, open carry legality is not directly associated with the firearm death rate. That said, one study did link the banning the open carry of unloaded handguns to decreased fatality rates [36].

Callcut et al. found banning open carry of unloaded handguns in California (where open carry of loaded guns is already illegal) to a decreased death rate [36]. Their finding, though, was based on a change in the law in a single state, which does limit the generalizability. Additionally, their finding was based on banning carry of unloaded handguns, which does not allow for comparison to our study results, as we define open carry law as the ability to carry a loaded handgun. Nevertheless, these possibly contradictory results warrant further study of open carry laws, especially as more states have legalized so-called 'Constitutional Carry,' which gives the legal gun owner the right to carry without additional permits.

While open carry legislation is understudied, there is no shortage of studies examining the impact of concealed carry laws on firearm-related deaths. A systematic review by the RAND Corporation, which aims explicitly to present nonpartisan scientific evidence, reported that shall-

issue concealed carry increases firearm homicide compared to no-issue or may-issue [14]. High-quality individual studies looking for an association between concealed carry laws and firearm-related deaths have had mixed results [5–9]. These mixed results are likely due to significant variations in study design and analysis and differences in outcome measures. For example, some studies look at all-cause firearm-related deaths, while some focus on firearm-related homicides. These mixed results concur with our results as on a univariable analysis, there was a significantly higher TFDR and FSR in states with permitless concealed carry, but no significant association in multivariable regression. Thus, we cannot make a definitive statement regarding the effect of concealed carry laws and suggest further works into the matter perhaps with time-based analyses.

There are several limitations to our study. First, are the inherent limitations of a retrospective cross-sectional study. Second, it only examines the most recent year of data – 2021. This was intentional as we wished to examine the most recent homicide and suicide rates as they have increased since the COVID-19 pandemic, and 2021 data is sparse in the literature. Finally, we did not include every variable associated with firearm-related deaths, which likely explains our regression model R^2 values (0.61–0.72), indicating we could not define a proportion of variance in the outcome by the involved covariates.

Further work is needed to validate the findings of our study. We also hope to get more granular data and explore ZIP Code- or city-level associations, as we understand firearm-related death rates in one part of a state may not be the same in another.

Our study found novel factors associated with firearm-related deaths, and strengthened the body of evidence for understudied factors. Overall, we highlight the complex interplay between state-level factors and firearm-related deaths and notes a difference in the influencing factors for firearm homicide and suicide. We confirm the association between firearm-related homicides and poverty, and firearm-related suicides and urbanization, with both significantly contributing to the total-firearm-related death rate. We found novel associations with state partisan lean and firearm-suicide and total firearm-related deaths. These findings underscore the need for a comprehensive and interdisciplinary approach to reducing firearm violence in the United States. We hope this study can spark discussion and additional research to help us better understand all factors associated with firearm-related deaths, aiming to decrease firearm violence and fatalities.

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Ethical approval statement

This study is exempt from Institutional Review Board due to using solely aggregate de-identified data.

CRediT authorship contribution statement

Emily A. Grimsley: conceptualization, methodology, software, investigation, data duration, formal analysis, writing – original draft, writing – review & editing, visualization
Meagan D. Read: conceptualization, verification, data curation, formal analysis, supervision
Michelle Y. McGee: investigation, resources, writing – original draft, writing – review & editing
Johnathan V. Torikashvili: investigation, resources, data curation
Noah T. Richmond: conceptualization, investigation
Haroon M. Janjua: methodology, software, verification, resources, data curation
Paul C. Kuo: conceptualization, methodology, formal analysis, writing – original draft, writing – review & editing, supervision, project administration.

Declaration of competing interest

The authors have no conflicts of interest to disclose. This study did not receive any extramural funding.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sopen.2023.07.011.

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