State gun laws, gun ownership, and mass shootings in the US: cross sectional time series

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ABSTRACT

OBJECTIVE

To determine whether restrictiveness-permissiveness of state gun laws or gun ownership are associated with mass shootings in the US.

DESIGN

Cross sectional time series.

SETTING AND POPULATION

US gun owners from 1998-2015.

EXPOSURE

An annual rating between 0 (completely restrictive) and 100 (completely permissive) for the gun laws of all 50 states taken from a reference guide for gun owners traveling between states from 1998 to 2015. Gun ownership was estimated annually as the percentage of suicides committed with firearms in each state.

MAIN OUTCOME MEASURE

Mass shootings were defined as independent events in which four or more people were killed by a firearm. Data from the Federal Bureau of Investigation's Uniform Crime Reporting System from 1998-2015 were used to calculate annual rates of mass shootings in each state. Mass shooting events and rates were further separated into those where the victims were immediate family members or partners (domestic) and those where the victims had other relationships with the perpetrator (non-domestic).

RESULTS

Fully adjusted regression analyses showed that a 10 unit increase in state gun law permissiveness was associated with a significant 11.5% (95% confidence interval 4.2% to 19.3%, P=0.002) higher rate of mass shootings. A 10% increase in state gun ownership was associated with a significant 35.1% (12.7% to 62.7%, P=0.001) higher rate of mass shootings. Partially adjusted regression analyses produced similar results, as did analyses restricted to domestic and non-domestic mass shootings.

CONCLUSIONS

States with more permissive gun laws and greater gun ownership had higher rates of mass shootings, and a growing divide appears to be emerging between restrictive and permissive states.

WHAT IS ALREADY KNOWN ON THIS TOPIC

More permissive state gun laws and higher levels of gun ownership are associated with higher levels of gun homicide and gun suicide in the US

WHAT THIS STUDY ADDS

States with more permissive gun laws and greater gun ownership have higher rates of mass shootings

There is a growing divergence in recent years as rates of mass shootings in restrictive states have decreased and those in permissive states have increased

Introduction

Despite an increasing frequency of mass shootings in the US and the seemingly disproportionate occurrence of mass shootings in some states and not others, little research has been carried out to understand state level factors that could influence mass shootings.[1] A 2018 report pointed to only three studies that had examined associations between gun laws and mass shooting events.[2-5] However, testing the effects of state gun laws on the occurrence of mass shootings was not the primary objective of at least one of these studies and the body of evidence they represent was inconclusive in terms of determining the effects of specific state gun laws on mass shootings.

Gun laws have the potential to influence the occurrence of mass shootings. There are limited national gun laws in the US, so the variety of state gun laws that have evolved provides an excellent opportunity for study. Previous studies have found that more permissive statewide gun laws are associated with higher levels of gun homicide and gun suicide,[6-10] although none of these studies considered whether state gun laws in general were associated with mass shootings. Gun ownership is also a potentially key variable to be examined in conjunction with gun laws, given that statewide gun ownership can lead to the implementation of laws, and the implementation of laws can result in changes to statewide gun ownership. Previous studies have found that gun ownership is associated with higher levels of gun assault and gun homicide, although none of these studies considered whether state gun ownership in general was associated with mass shootings.[11-15]

How gun laws and gun ownership influence mass shooting events in the US is not fully understood. Therefore, we conducted a cross sectional, time series analysis to broadly examine whether restrictiveness or permissiveness of state gun laws and state gun ownership were associated with mass shootings.

Methods

Independent variables

We used the 1998-2015 edition of the *Traveler's Guide to the Firearms Laws of the Fifty States* to obtain the independent variable of interest, an annual restrictiveness-permissiveness scale of US gun laws for each state.[16] This report is published annually by legal professionals as a reference guide for gun owners traveling between states and gives a rating between 0 (completely restrictive) and 100 (completely

permissive) for the firearm laws of all 50 states. The report considers more than 13 factors in developing the score, including: standard firearms ownership and permit requirements; if semi-automatic, high capacity magazines, machine guns, and suppressors are permitted or restricted; if the firearms laws across the state vary widely; if the state employs a right to self-defense, ability to conceal, ability to open and vehicle carry, ability to conceal carry in state parks, or whether a gun permittee can carry in a restaurant serving alcohol; whether there is a duty to notify law enforcement of permit status; and if one can keep a gun in their vehicle at colleges and K-12 schools (primary and secondary schools).

Gun ownership is not directly surveyed across all 50 states each year in the US. A review of over 24 gun ownership indicators found that the percentage of suicides committed with a firearm was the best measure for estimating gun ownership by state.[17] This has also been verified in several other studies across different regions,[18-22] in which the percentage of suicides committed with a firearm was shown to be highly correlated with the proportion of households reporting gun ownership (across 21 US states r=0.90,[23] across nine census regions r=0.93[24]). Therefore, we chose to use the percentage of suicides committed with a firearm as a proxy measurement for gun ownership per state per year, which we obtained through the Centers for Disease Control and Prevention's online database, WONDER.[25]

We included the following annual measures of state-level characteristics in our analyses: median household income, percent high school graduation, percent female headed households, percent in poverty, percent unemployment, incarceration rate, and percent white. We took all covariates from the American Community Survey at the United States Census Bureau,[26] except incarceration rate, which was obtained from the Bureau of Justice Statistics.[27] We included year in all analyses as a fixed effect to account for other time varying factors.

Outcome variables

We used the Supplementary Homicide Reports from the Federal Bureau of Investigation's Uniform Crime Reporting System (1998-2015) to obtain counts of mass shootings by state.[28] We compiled these data in line with the most commonly used definition of a mass shooting: one event in which four or more individuals were killed by a perpetrator using a firearm and the perpetrator themselves did not count toward the total number of victims.[29 30] These mass shooting events were analyzed in total and stratified as to whether the mass shooting was domestic or non-domestic in nature. Domestic mass shootings included instances where the perpetrator committed the act against an immediate family member or partner. Non-domestic mass shootings included all other types of relationships, such as acquaintances, employees, employers, friends, neighbors, strangers, extended family members, and others. Florida was excluded due to non-participation in the Uniform Crime Reporting System program.[31]

Descriptive and unadjusted analyses

To understand how state gun law restrictiveness-permissiveness scores changed over the study period, we first estimated an ordinary least squares regression with year as the independent variable and permissiveness score as the dependent variable. We also calculated boxplots of the distribution of restrictiveness-permissiveness scores per state across all years. We stratified states with restrictiveness-permissiveness scores ≤50 (labeling them restrictive) and >50 (labeling them permissive). For comparative purposes, we also used a second stratification that separated states by the median restrictiveness-permissiveness score of ≤79 (restrictive) and >79 (permissive). We compared both stratifications with changes in mass shootings per million people over time. Average state restrictiveness-permissiveness scores and average state gun ownership percentages were calculated across all years of available data. We calculated Pearson correlation coefficients and scatterplots between these state restrictiveness-permissiveness scores and gun ownership percentages, as well as the population-based rates of mass shootings across all states in all years.

Regression analyses

Data were analyzed by using generalized estimating equations with a negative binomial distribution and natural log link to determine the association between state gun laws and annual mass shootings. We chose this regression specification because of estimated variances exceeding conditional means. Repeated cross-sectional time-series measures were calculated as state-per-year. We used an offset of state population and, in the fully adjusted model, median household income, percent high school graduation, percent female headed households, percent in poverty, percent unemployment, incarceration rate, and percent white were included as covariates. These variables were chosen according to suggestions in the Supplementary Homicide Reports documentation,[28] as well as other studies that examined state laws with different firearm outcomes.[6-10 32] We included year as an indicator variable in all analyses. A compound symmetry working correlation structure was assumed due to its best fit of the data as shown by consistently lowest quasi-likelihood under the independence model criterion among the datasets.

Fully adjusted models included all covariates and an indicator variable for year. Partially adjusted models were calculated by including confounders that changed the association between the restrictiveness-permissiveness score and the rate of mass shootings by more than 10%, a common method for confounder selection.[33 34] Partially adjusted models also included an indicator variable for year and avoided inclusion of less influential covariates that added limited information to our models. Restrictiveness-permissiveness score and incarceration rate were lagged by one year to account for reverse causation. Because restrictiveness-permissiveness of state

gun laws and state gun ownership were highly and significantly correlated (Pearson's r 0.79, P<0.001) and interdependent, we did not include them in the same regression models.

Patient and public involvement

Neither patients nor the public were involved in the planning or execution of this study.

Results

Descriptive and unadjusted analyses

The average restrictiveness-permissiveness score of state gun laws showed an overall shift toward permissiveness from 1998-2014; for each additional year that passed, scores on average became more permissive by 0.16 units (P=0.005). From 1998-2014, there were 344 mass shootings incidents as reported by the Uniform Crime Reports. A total of 263 (76.5%) of these events were classified as non-domestic events, the remaining 81 (23.5%) were classified as domestic. The variability of restrictiveness-permissiveness scores over the study period was limited in most states. Massachusetts was found to have the most restrictive and Vermont the most permissive state gun laws over the study period (see supplementary fig 1).

Yearly changes in rates of mass shootings showed that restrictive states, on average, had lower rates of mass shootings compared with permissive states across most years. Figure 1 shows that a growing divergence was noted in 2010 with a decreasing rate of mass shootings in restrictive states and an increasing rate of mass shootings in permissive states. Scatterplots of gun law restrictiveness-permissiveness scores, gun ownership, and rates of mass shooting showed positive and significant correlations between gun ownership and rates of mass shootings (Pearson's r 0.42, P=0.003), gun law restrictiveness-permissiveness and rates of mass shootings (0.38, P=0.007), and gun law restrictiveness-permissiveness and gun ownership (0.79, P<0.001).Figure 2 shows that on average, more permissive states and states with higher rates of gun ownership had more mass shootings in these unadjusted, bivariate analyses.

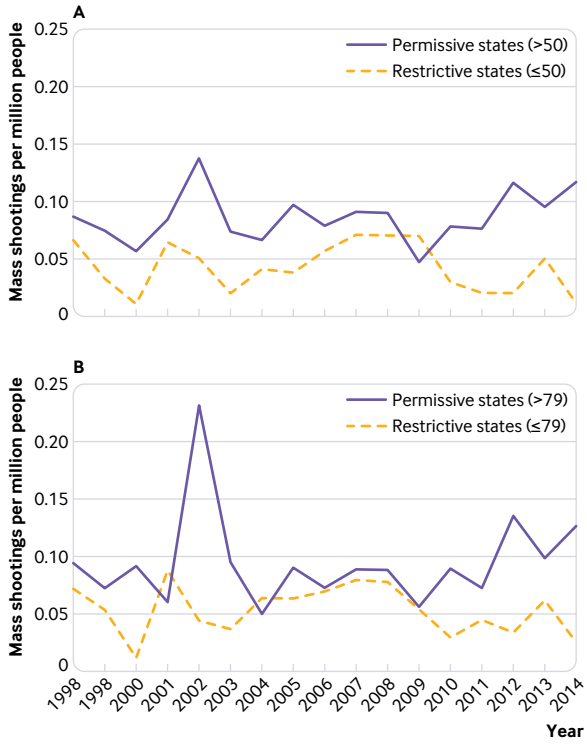

Fig 1 | Rates of mass shootings over time in restrictive versus permissive states for a restrictiveness-permissiveness score of 50 (A) and 79 (B). Years 1998-2014 were included because of the lag of the permissiveness score

Fully adjusted and partially adjusted analyses of all mass shooting outcomes

Table 1 shows that in fully adjusted models, a 10 unit increase in state gun law permissiveness was associated with a significant 11.5% (95% confidence interval 4.2% to 19.3%, P=0.002) higher rate of mass shootings. A 10% increase in state gun ownership was associated with a significant 35.1% (12.7% to 62.7%, P=0.001) higher rate of mass shootings.

In partially adjusted models, an indicator variable for year was included in all analyses, in addition to only covariates that changed the relation between the exposures of interest (restrictiveness-permissiveness and gun ownership) and mass shootings by greater than 10%. For state gun law restrictiveness-permissiveness, only median income fulfilled this criterion. For state gun ownership, no covariate changed the relation by even 5% so only year was included. Table 1 shows that a 10 unit increase in state permissiveness was associated with a significant 9.2% (95% confidence interval 1.7% to 17.2%, P=0.01) higher rate of mass shootings. A 10% higher state firearm ownership rate was associated with a significant 36.1% (20.1% to 54.2%, P<0.001) higher rate of mass shootings.

Analyses of non-domestic and domestic mass shooting outcomes

Table 2 shows that in the fully adjusted model that was restricted to non-domestic mass shooting outcomes only, for every 10 unit increase in state gun law permissiveness, there was a significant 11.3% (95% confidence interval 2.4% to 20.9%, P=0.01) higher rate of mass shootings. In the partially adjusted model (where only year and median income were included as covariates), there was a significant 8.5% (1.0% to 16.5%, P=0.02) higher rate of mass shootings. For every 10 unit increase in state gun ownership in the fully adjusted model, there was a significant 32.7% (9.1% to 61.4%, P=0.005) higher rate of mass shootings. In the partially adjusted model there was a significant 38.8% (22.4% to 57.3%, P<0.001) higher rate of mass shootings.

Table 2 shows that in the fully adjusted model that was restricted to domestic mass shooting outcomes only, for every 10 unit increase in state law permissiveness, there was a significant 14.0% (95% confidence interval 0.8% to 28.9%, P=0.04) higher rate of mass shootings. In the partially adjusted model, there was an non-significant 13.2% (−3.1% to 32.3%,

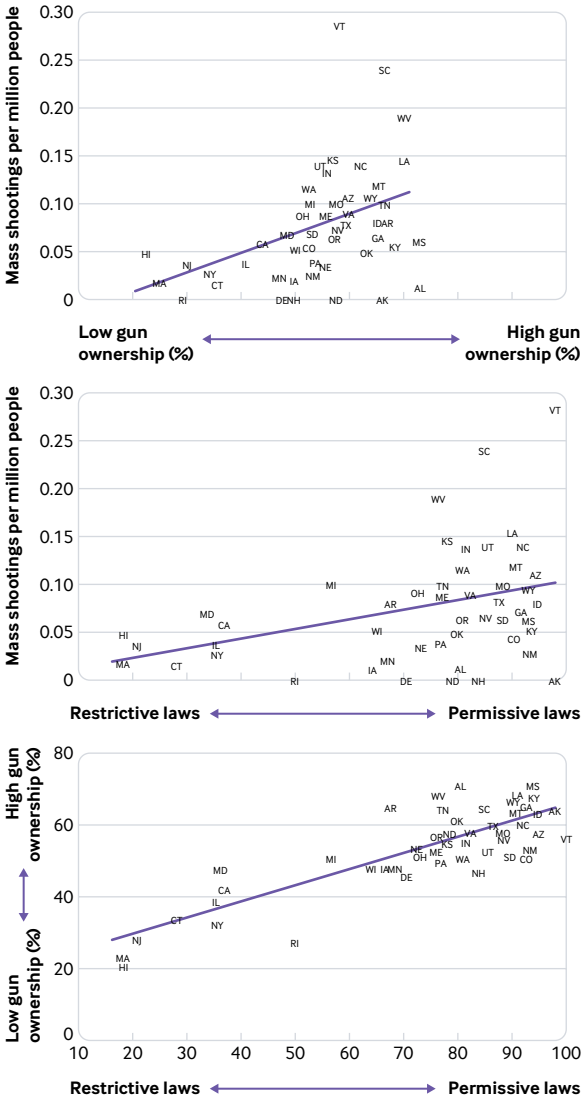

Fig 2 | Scatterplots of the relations between state rates of mass shootings, gun law restrictiveness-permissiveness scores, and gun ownership

P=0.12) higher rate of mass shootings. For every 10 unit increase in state gun ownership in the fully adjusted model, there was a significant 60.3% (17.3% to 118.9%, P=0.003) higher rate of mass shootings. In the partially adjusted model, there was a borderline non-significant 31.2% (−1.7% to 75.0%, P=0.06) higher rate of mass shootings.

Discussion

Our analyses show that US state gun laws have become more permissive in recent decades, and that a growing divide in rates of mass shootings appears to be emerging between restrictive and permissive states. A 10 unit increase in the permissiveness of state gun laws was associated with an approximately 9% higher rate of mass shootings after adjusting for key factors. A 10% increase in gun ownership was associated with an approximately 35% higher rate of mass shootings after adjusting for key factors. On the absolute scale, this means that a state like California, which has approximately two mass shootings per year, will have an extra mass shooting for every 10 unit increase in permissiveness over five years. It will also have three to five more mass shootings per five years for every 10 unit increase in gun ownership. These results were also consistent across multiple analyses and when stratified as to whether or not mass shootings were committed by someone in a close relationship with the victims.

Previous research

These associations between state gun laws, gun ownership, and mass shootings are analogous to what was found in previous research for other types of gun injuries.[6-10] To develop effective state gun laws, the underlying cause of the association with rates of mass shootings needs to be identified. Perhaps as a result of outside pressures, relatively few specific gun laws have been scientifically studied, much less proven effective, for gun violence outcomes in general, and mass shootings in particular.[2 35] Domestic violence and suicide are commonly connected to mass shooting events, so state gun laws involving restraining orders and extreme risk protection orders may be valuable first opportunities for scientific evaluation.[36 37] Non-legislative approaches, such as environmental modifications, policing practices, and bystander training, could also be worthy of evaluation in potentially preventing and reducing the tragic impacts of mass shootings.[38-41] As with other large-scale, population-wide solutions to relatively infrequent mass health threats, both legislative and non-legislative approaches should be carefully studied for their potential beneficial effects as well as any unintended consequences that could emerge. This caveat is applicable here given the low rate of mass shootings compared with daily shooting events, although certain solutions could benefit both events.[42-46]

Strengths and limitations

There are several limitations to our study. Our study design incorporated a time series component, lagged variables, and multiple covariate adjustment strategies,

Table 1 | Percent changes in relative rate of mass shootings for every 10 unit change in state gun law permissiveness or state gun ownership

Exposure	Fully adjusted % change estimate (95% CI)	Partially adjusted % change estimate (95% CI)
State gun law permissiveness	11.5* (4.2 to 19.3)	9.2† (1.7 to 17.2)
State gun ownership	35.1* (12.7 to 62.7)	36.1‡ (20.1 to 54.2)

*P<0.01
†P<0.05
‡P<0.001

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Table 2 | Percent changes in relative rate of mass shootings for every 10 unit change in state gun law permissiveness and state gun ownership separated into non-domestic and domestic categories

	Fully adjusted % change estimate (95% CI)		Partially adjusted % change estimate (95% CI)	
Exposure	Non-domestic	Domestic	Non-domestic	Domestic
State gun law permissiveness	11.3* (2.4 to 20.9)	14.0* (0.8 to 28.9)	8.5* (1.0 to 16.5)	13.2 (−3.1 to 32.3)
State gun ownership	32.7† (9.1 to 61.4)	60.3† (17.3 to 118.9)	38.8‡ (22.4 to 57.3)	31.2 (−1.7 to 75.0)

*P<0.05
†P<0.01
‡P<0.001

and was primarily able to show broad associations between state gun laws, gun ownership, and mass shootings. The potential for omitted variable biases and reverse causation remain and future analyses are encouraged to build on our work by testing the before-and-after effects of enactment or repeal of gun laws in specific states, or both, alongside appropriately matched control states.

In addition, the state restrictiveness-permissiveness score we used has not been validated. However, this score had a wide range (0-100), was determined by legal professionals for use by actual gun owners, had nearly two decades of consistent data, and was highly correlated with other similar state-level scales that had been previously used (r=0.85).[6] State gun laws and the enforcement of these laws can be difficult to separate and our measure of state gun laws might not reflect differing levels of enforcement among states with comparable restrictiveness-permissiveness scores.

There are concerns about potential under-reporting in the Uniform Crime Reporting System Supplemental Homicide reports due to some states failing to consistently report. However, these under-reported data would likely bias our results toward the null. If errors were randomly distributed, then there would be non-differential misclassification, leading to an underestimate of our association. Alternatively, if there is differential misclassification, evidence points to it being among more permissive states (such as Alabama, Nebraska, and Florida) most likely leading to, if anything, underestimation in the associations we found. Despite this, improved reporting systems for mass shootings, including better tracking of whether mass shooters legally possessed their firearms or crossed state lines to obtain their weapons, or both,[47 48] are needed to further improve the accuracy and detail of future analyses.

Conclusion and future directions

The permissiveness or restrictiveness of state gun laws is associated with the rate of mass shootings in the US. States with more permissive gun laws and greater gun ownership have higher rates of mass shootings, and a growing divergence is noted in recent years as rates of mass shootings in restrictive states have decreased and those in permissive states have increased. Better data collection on mass shootings and more studies that test changes to specific state gun laws, compared with states that have not made changes, are necessary based on our findings, the general increase in state gun law permissiveness, and the pressing need reduce mass shootings in the US.

Contributors: All authors participated in the writing, editing, creation, and approval of this paper. PMR assembled the data, conducted the analyses, and wrote and edited the original manuscript. CCB first conceptualized the paper and participated in data preparation, analysis, writing, and editing. All authors had full access to the data in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis. PMR is the guarantor. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting these criteria have been omitted.

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Competing interests: All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organization for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Ethical approval: Owing to the aggregated nature of the count data used in the study, the Institutional Review Board at Columbia University determined that the study was exempt.

Patient consent: Not applicable.

Data sharing: Statistical code and dataset available from the corresponding author.

The lead author (PMR) affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned have been explained.

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Supplementary materials: Supplementary figure 1