The Relationship Between Gun Ownership and Firearm Homicide Rates in the United States, 1981–2010

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Objectives. We examined the relationship between levels of household firearm ownership, as measured directly and by a proxy—the percentage of suicides committed with a firearm—and age-adjusted firearm homicide rates at the state level.

Methods. We conducted a negative binomial regression analysis of panel data from the Centers for Disease Control and Prevention's Web-Based Injury Statistics Query and Reporting Systems database on gun ownership and firearm homicide rates across all 50 states during 1981 to 2010. We determined fixed effects for year, accounted for clustering within states with generalized estimating equations, and controlled for potential state-level confounders.

Results. Gun ownership was a significant predictor of firearm homicide rates (incidence rate ratio = 1.009; 95% confidence interval = 1.004, 1.014). This model indicated that for each percentage point increase in gun ownership, the firearm homicide rate increased by 0.9%.

Conclusions. We observed a robust correlation between higher levels of gun ownership and higher firearm homicide rates. Although we could not determine causation, we found that states with higher rates of gun ownership had disproportionately large numbers of deaths from firearm-related homicides. (*Am J Public Health.* Published online ahead of print September 12, 2013: e1–e8. doi:10.2105/AJPH.2013.301409)

The December 14, 2012, tragic shooting of 20 children and 7 adults in Newtown, Connecticut, brought the issue of controlling firearm-related mortality to the forefront.[1–5] The National Rifle Association responded by calling for armed guards and teachers in all schools.[6] Hundreds of teachers have flocked to gun-training classes, motivated by the contention that increasing the presence of guns can reduce firearm-related deaths.[7] Firearms are responsible for more than 31 000 deaths and an estimated 74 000 nonfatal injuries among US residents each year,[8] most of which are violence related. Understanding the relationship between the prevalence of gun ownership (and therefore the availability of guns) and firearm-related mortality is critical to guiding decisions regarding recently proposed measures to address firearm violence.

Several lines of research have explored the relationship between firearm prevalence and homicide rates.[9] Studies have shown that individual gun ownership is related to an increased risk of being a homicide victim.[10–12] These studies are limited because they only examine the individual risks or benefits of gun ownership. They cannot be used to assess whether the prevalence of gun ownership in the population affects overall homicide rates.[9] Ecological studies have correlated higher levels of gun ownership rates in the United States with higher national rates of homicide than are experienced in other countries.[13–19] Although these studies suggest a relationship between gun ownership and homicide, they are severely limited because of inadequate adjustment for confounding factors.[9]

Examination of variation in homicide rates between cities, regions, or states within the United States in relation to differences in gun ownership provides a stronger line of research. A few studies have used a time-series design to investigate the relationship between firearm ownership and homicide over a period of years, either analyzing changes over time within cities or states[20–23] or examining changes over time across states.[24–29] Several studies used cross-sectional analyses to detect a positive relationship between the prevalence of gun ownership at the neighborhood,[30] county,[31,32] regional,[31,33–36] or state level[32,34–45] and homicide rates, with control for differences in factors associated with homicide (e.g., urbanization, race/ethnicity, unemployment, poverty, crime, and alcohol use). Most data used in these studies represented only a cross-section in time; only 4 contained panel data over multiple years. Sorenson and Berk used data from 1972 to 1993,[23] Bordura examined data for 1973 to 1981,[31] Miller et al. published 3 analyses of panel data from 1988 to 1997,[34–36] and Cook and Ludwig used panel data for 1980 to 1999.[32] None of the existing panel studies examined data more recent than 1999.[32]

Studies analyzing data over long periods are valuable because they assess the effects of variation in gun availability not only between states but within states over time. Although we are aware of no multiyear studies of interstate variation in gun ownership and homicide rates since 1999, national data from the General Social Survey show that the prevalence of household gun ownership has decreased by approximately 12% since then.[46] This presents an opportunity not only to bring the existing literature up to date, but also to investigate temporal changes in gun ownership to explore its potential relationship with changes in homicide rates, within and between states. Annual, state-specific homicide data are readily available from as early as 1981 and as recently as 2010.[8] During this period, the prevalence of gun ownership decreased by about 36%.[46] Thus, it is feasible and useful to study the relationship between gun availability and homicide across states over the entire period 1981 to 2010.

We expanded on previous work by incorporating the most recent data, analyzing data over 3 decades, and controlling for an extensive panel of annual, state-specific factors that might confound the association between gun ownership and firearm homicide rates. We examined the relationship between gun ownership and age-adjusted firearm homicide rates across all 50 states during the 30-year period 1981 through 2010, with adjustment for age, gender, race/ethnicity, urbanization, poverty, unemployment, income, education, income inequality, divorce rate, alcohol use, violent crime rate, nonviolent crime rate, hate crime rate, number of hunting licenses, age-adjusted nonfirearm homicide rate, incarceration rate, and suicide rate. To the best of our knowledge, this was the most comprehensive study to date, both in number of years in the analysis and breadth of control variables.

METHODS

We assembled a panel of annual data for 1981 to 2010 for each of the 50 states. We modeled the adjusted firearm homicide rate in a given year for a given state as a function of the gun ownership level in that state during that year, with adjustment for factors that could confound the association. We used a negative binomial regression model, entering fixed effects for each year. We accounted for clustering of observations among states with a generalized estimating equation (GEE) approach.

Variables and Data Sources

The outcome variable was the age-adjusted firearm homicide rate, obtained from the Centers for Disease Control and Prevention's Web-Based Injury Statistics Query and Reporting Systems database.[8] Although death classification changed from the 9th to the 10th revision of the *International Classification of Diseases*[47,48] during the study period, a comparability analysis showed no significant differences in the classification for either suicide or homicide.[49]

The main predictor variable was the prevalence of household firearm ownership. Because no annual survey assessed the level of household firearm ownership in all 50 states during the entire study period, we used a well-established proxy: the percentage of suicides committed with a firearm (firearm suicides divided by all suicides, or FS/S). This measure has been extensively validated in the literature[13,14,32,37,44,50–54] and has been determined to be the best proxy available of many that have been tested.[50] The ratio of firearm suicides to all suicides has been shown to correlate highly with survey measures of household firearm ownership,[13,14,32,36,50–54] including state-specific measures of firearm ownership,[36,50] and has been used extensively as a proxy for state-specific gun availability in previous studies.[32,34–37,39,43,44,54–56]

In 2001, 2002, and 2004, the Behavioral Risk Factor Surveillance System surveys measured the prevalence of household gun ownership in all 50 states. We found the correlation between our proxy measure, FS/S, and the surveillance system estimates for the 50 states for 2001, 2002, and 2004 to be 0.80.

We controlled for the following factors, which have been identified in previous literature[29,32,34–37,41–45,54,56,57] as being related to homicide rates: proportion of young adults (aged 15–29 years),[8] proportion of young males (aged 15–29 years),[8] proportion of Blacks,[8] proportion of Hispanics,[58] level of urbanization,[59] educational attainment,[60] poverty status,[61] unemployment,[62] median household income,[63] income inequality (the Gini ratio),[64] per capita alcohol consumption,[65] nonhomicide violent crime rate (aggravated assault, robbery, and forcible rape),[66] nonviolent (property) crime rate (burglary, larceny–theft, and motor vehicle theft),[66] hate crime rate,[67] prevalence of hunting licenses,[68] and divorce rate.[69] To account for regional differences, we controlled for US Census region.[70] In addition, to capture unspecified factors that may be associated with firearm homicide rates, we controlled for the annual, age-adjusted rate of nonfirearm homicides in each state.[8] We also controlled for state-specific incarceration rates[71] and suicide rates.[8] The definitions and sources of these data are provided in Table 1.

Where values of a variable in some years were missing or unavailable, we interpolated data from surrounding years or extrapolated from the 2 closest years. All interpolations and extrapolations were linear. We did not, however, impute values for the outcome variable. State-level mortality data obtained through the Web-Based Injury Statistics Query and Reporting Systems for 2008 to 2010 are subject to a stringent censoring threshold not applied for earlier years in the study period, and results are not reported if fewer than 10 homicide deaths occurred. This resulted in a total of 13 missing data points for the outcome variable during the final 3 years of the study period. We excluded these data points; therefore, our data set had a total of 1487 observations.

Model and Statistical Analysis

Because the outcome variable—the age-adjusted firearm homicide rate—was skewed rather than normally distributed, and because overdispersion was present in the data (the variance greater than the mean), we modeled this outcome with a negative binomial model, following the approach taken in previous studies.[34–36,41,55,57,72,73] Estimation of the overdispersion parameter confirmed our choice of a negative binomial model over a Poisson model,[74] following Miller et al.[34]

Clustering in our data could have arisen in 2 ways: by year (30 levels) and by state (50 levels). We entered year as a fixed effect in the regression model. This allowed us to control for any national, secular changes that could affect firearm homicide rates. To account for clustering of observations among states, we used a GEE approach.[75] This procedure accounts for correlation of data within state clusters, avoiding a type 1 error that would be introduced if this correlation were ignored.[76] We used an exchangeable (compound symmetry) working correlation matrix to model the correlation among observations within states. We used robust variance estimators (the Huber–White sandwich estimator of variance) to produce consistent point estimates[75,77] and SEs[75,77,78] even if the working correlation matrix was misspecified. Our approach followed that of Miller et al., who used a GEE approach to account for clustering by region in their study of the impact of gun ownership on suicide rates.[55]

Because our primary aim was to examine the relationship between gun prevalence and homicide rates, with adjustment for all identified potential confounding variables, we first ran a full model that incorporated all variables, regardless of their contribution to the model. To develop a final, more parsimonious model, we first entered all variables found to be significant in bivariate analyses (we used a Wald test at a significance level of .10) into 1 model. We then deleted variables found not to be significant in the presence of the other variables, assessing the significance of each

TABLE 1—Variables and Data Sources in Study of Gun Ownership and Firearm Homicide Rates: United States, 1981–2010

Variable	Definition	Source	Notes
Firearm homicides	Rate/100 000 population, adjusted to 2000 age distribution	WISQARS[8]	Missing data for NH 2008–2010; ND 2008–2010; VT 2008–2010; WY 2008, 2010; HI 2010; SD 2010
Prevalence of gun ownership	Proportion of suicides committed with a firearm	WISQARS[8]	Complete panel series[a]
Age	Percentage of population aged 15–29 y	WISQARS[8]	Complete panel series[a]
Gender	Percentage of population aged 15–29 y who are male	WISQARS[8]	Complete panel series[a]
Race/ethnicity			
Black	Percentage of Blacks in population	WISQARS[8]	Complete panel series[a]
Hispanic	Percentage of Hispanics in population	US Census Bureau[58]	Complete panel series[a]
Poverty	Percentage of population living in poverty	US Census Bureau[61]	Complete panel series[a]
Unemployment	Percentage unemployed among civilian labor force, aged ≥ 16 y	US Bureau of Labor Statistics[62]	Complete panel series[a]
Household income	Median household income (in 2010 dollars)	US Bureau of the Census[63]	Data extrapolated for 1981–1983
Educational attainment	Percentage of adults aged ≥ 25 y with college degree (≥ bachelor's)	US Census Bureau[60]	Data interpolated for 1981–1988 and 1992
Income inequality	Gini coefficient	US Census Bureau[64]	Data interpolated for 1981–1988, 1990–1998, 2000–2005; variable rescaled in final model to ease interpretation of parameter estimate
Urbanization	Percentage of population living in urbanized area or urban cluster	US Census Bureau[59]	Data interpolated for 1991–1999 and 2001–2009; data extrapolated for 1981–1989 because 1980 Census definition of urban was different
Alcohol	Per capita alcohol consumption among persons aged ≥ 14 y	National Institute of Alcoholism and Alcohol Abuse[65]	Complete panel series[a]
Violent crime	Rates of aggravated assault, robbery, and forcible rape/100 000 population	Federal Bureau of Investigation[66]	Complete panel series[a]; variable rescaled in final model to ease interpretation of parameter estimate
Nonviolent crime	Rate of property crime (burglary, larceny-theft, and motor vehicle theft)/100 000 population	Federal Bureau of Investigation[66]	Complete panel series[a]; variable rescaled in final model to ease interpretation of parameter estimate
Hate crime	Rate of hate crimes against persons/1 000 000 population	Federal Bureau of Investigation[67]	Data available for 1995–2010; data from 1995 used for 1981–1994
Divorce	Rate/1000 population	National Center for Health Statistics[69]; US Census Bureau[59]	Data interpolated for 1986 in all states, interpolated for many years for CA, GA, HI, IN, LA, and MN
Hunting licenses	Proportion of population aged ≥ 15 y licensed	US Fish and Wildlife Service[68]	Complete panel series[a]
Region	Census region	US Census Bureau[70]	Complete panel series[a]
Nonfirearm homicides	Rate/100 000 population, adjusted to 2000 age distribution	WISQARS[8]	Missing data for NH 2008–2010; ND 2008–2010; VT 2008–2010; WY 2008, 2010; HI 2010; SD 2010
Incarceration	Prisoners with sentence of > 1 y/100 000 population	Bureau of Justice Statistics[71]	Data interpolated for 1981, 1982, and 1992
Suicide	No./100 000 population	WISQARS[8]	Complete panel series[a]

Note. WISQARS = Web-Based Injury Statistics Query and Reporting Systems.
[a]All 50 states, 1981–2010.

variable with a Wald test at a significance level of .05. Finally, we added each of the excluded variables into the model, 1 at a time, to assess whether it became significant when included in a model with the other variables. We included fixed effects for year and clustering by state in all models.

As a check on the robustness of the results, we also ran a negative binomial model with fixed effects for both year and state. Because of the large number of variables in this model, we reported only the statistically significant predictors in this version of the final model. We conducted all analyses with the XTNBREG and NBREG procedures in Stata version 12 (StataCorp LP, College Station, TX).

RESULTS

Over the 30-year study period, the mean estimated percentage of gun ownership (measured by the FS/S proxy) ranged from a low of 25.8% in Hawaii to a high of 76.8% in Mississippi, with an average over all states of 57.7% (Appendix A, available as a supplement to the online version of this article at http://www.ajph.org). Among the 50 states, the average percentage of gun ownership (measured by the FS/S proxy) decreased from 60.6% in 1981 to 51.7% in 2010. By decade, this percentage declined from 60.6% in 1981 to 1990 to 59.6% in 1991 to 2000 to 52.8% in 2001 to 2010.

Over the study period, the mean age-adjusted firearm homicide rate ranged from a low of 0.9 per 100 000 population in New Hampshire to a high of 10.8 per 100 000 in Louisiana, with an average over all states of 4.0 per 100 000 (Appendix A). Among the 50 states, the average firearm homicide rate decreased from 5.2 per 100 000 in 1981 to 3.5 per 100 000 in 2010. By decade, this rate was 4.2 per 100 000 in 1981 to 1990, 4.3 per 100 000 in 1991 to 2000, and 3.4 per 100 000 in 2001 to 2010.

In a bivariate analysis (a GEE negative binomial model with year fixed effects and accounting for clustering by state, but without any other predictor variables besides gun ownership), the gun ownership proxy was a significant predictor of firearm homicide rates (incidence rate ratio [IRR] = 1.011; 95% confidence interval [CI] = 1.005, 1.018).

The final GEE negative binomial model revealed 6 significant predictors of firearm homicide rates: gun ownership proxy (IRR = 1.009; 95% CI = 1.004, 1.014), percentage Black, income inequality, violent crime rate, nonviolent crime rate, and incarceration rate (Table 2). This model indicates that for each 1 percentage point increase in the gun ownership proxy, the firearm homicide rate increased by 0.9%.

In the final model, rerun with standardized predictor variables to ease interpretation of results, the IRR for the gun ownership proxy was 1.129 (95% CI = 1.061, 1.201), indicating that for each 1-SD increase in the gun ownership proxy, the firearm homicide rate increased by 12.9% (Table 3).

After we controlled for all the measured potential confounding variables, rather than just those found significant in the final model, the gun ownership proxy was still a significant predictor of firearm homicide rates (IRR = 1.008; 95% CI = 1.004, 1.012; Table 4). This result did not change after we excluded the 6 states with missing data for homicide rates in 1 or more years. When we restricted the analysis to 2001, 2002, and 2004 (years for which the Behavioral Risk Factor Surveillance System directly measured household gun ownership in all 50 states), the magnitude of the IRR estimated with the proxy measure (FS/S) was similar to that estimated with the survey measure of state-specific household gun ownership, but it was not statistically significant. The IRR associated with gun ownership also remained the same when we executed the full model with PROC GENMOD in SAS version 9.1 (SAS Institute, Cary, NC) rather than the XTNBREG procedure in Stata. We also found little change in the results when we omitted all variables with 1 or more interpolated or extrapolated values from the analysis.

When we lagged the gun ownership proxy by 1 year, it remained a significant predictor of firearm homicide rates (IRR = 1.009; 95% CI = 1.005, 1.013; Table 4). When we lagged the gun ownership proxy by 2 years, its effect was attenuated, although still positive and significant (IRR = 1.005; 95% CI = 1.001, 1.009).

We found little change in the magnitude or significance of the parameter estimate for the gun ownership proxy variable when we introduced linear and quadratic time variables into the analysis to model temporal changes in homicide rates or when the data were weighted by the square root of state population (Table 4). Use of a Poisson rather than a negative binomial model did not alter the results.

In a negative binomial model with both year and state fixed effects, the gun ownership proxy

TABLE 2—Results of Final Model for Significant Predictors of Age-Adjusted Firearm Homicide Rate: United States, 1981–2010

Variable	IRR (95% CI)	*P*	Interpretation
Gun ownership	1.009 (1.004, 1.014)	.001	For each 1 percentage point increase in proportion of household gun ownership, firearm homicide rate increased by 0.9%
Percentage Black	1.052 (1.037, 1.068)	.001	For each 1 percentage point increase in proportion of Black population, firearm homicide rate increased by 5.2%
Gini coefficient	1.046 (1.003, 1.092)	.037	For each 0.01 increase in Gini coefficient, firearm homicide rate increased by 4.6%
Violent crime rate	1.048 (1.010, 1.087)	.013	For each increase of 1/1000 in violent crime rate, firearm homicide rate increased by 4.8%
Nonviolent crime rate	1.008 (1.003, 1.013)	.002	For each increase of 1/1000 in nonviolent crime rate, firearm homicide rate increased by 0.8%
Incarceration rate	0.995 (0.991, 0.999)	.027	For each increase of 1/10 000 in incarceration rate, firearm homicide rate decreased by 0.5%

Note. CI = confidence interval; IRR = incidence rate ratio. Final model incorporated only variables whose parameter estimates were significant at the $P < .05$ level. Model included fixed effects for year and adjustment for clustering within states.

TABLE 3—Results of Final Model for Significant Predictors of Age-Adjusted Firearm Homicide Rate, Using Standardized Predictor Variables: United States, 1981–2010

Variable	IRR (95% CI)	P	Interpretation
Gun ownership	1.129 (1.061, 1.201)	.001	For each 1-SD increase in proportion of household gun ownership, firearm homicide rate increased by 12.9%
Percentage Black	1.828 (1.536, 2.176)	.001	For each 1-SD increase in proportion of black population, firearm homicide rate increased by 82.8%
Gini coefficient	1.129 (1.007, 1.266)	.037	For each 1-SD increase in Gini coefficient, firearm homicide rate increased by 12.9%
Violent crime rate	1.154 (1.031, 1.291)	.013	For each 1-SD increase in violent crime rate, firearm homicide rate increased by 15.4%
Nonviolent crime rate	1.100 (1.036, 1.168)	.002	For each 1-SD increase in nonviolent crime rate, firearm homicide rate increased by 10.0%
Incarceration rate	0.928 (0.868, 0.992)	.027	For each 1-SD increase in incarceration rate, firearm homicide rate decreased by 7.8%.

Note. CI = confidence interval; IRR = incidence rate ratio. Final model incorporated only variables whose parameter estimates were significant at the $P < .05$ level. Model included fixed effects for year and adjustment for clustering within states.

remained a significant predictor of firearm homicide rates (IRR = 1.010; 95% CI = 1.001, 1.019). Percentage Black and violent crime rate were also significant predictors of firearm homicide in this model (data not shown).

To investigate whether our proxy measure of gun ownership also predicted non–firearm-related homicides, we repeated the analyses with the age-adjusted nonfirearm homicide rate as the outcome variable. The gun ownership proxy was not a significant predictor of nonfirearm homicide rates in either the full (IRR = 1.001; 95% CI = 0.998, 1.005; $P = .52$) or final (IRR = 0.999; 95% CI = 0.996, 1.003; $P = .78$) models (data not shown).

To address the potential problem of serial autocorrelation, we ran a set of 30 year-specific negative binomial regressions. Because of the small number of data points, we ran parsimonious models with only a few predictors. Starting with our final model, we included only covariates that were significant predictors of homicide rates in at least 2 of the year-specific regressions (percentage Black, income inequality, violent crime rate, and gun ownership proxy). The gun ownership proxy was statistically significant in 26 of the 30 year-specific models, with an IRR in these 30 regressions ranging from 1.009 to 1.022.

DISCUSSION

To the best of our knowledge, ours is the most up-to-date and comprehensive analysis of the relationship between firearm ownership and gun-related homicide rates among the 50 states. Our study encompassed a 30-year period, with data through 2010, and accounted for 18 possible confounders of the relationship between gun ownership and firearm homicide. We found a robust relationship between higher levels of gun ownership and higher firearm homicide rates that was not explained by any of these potential confounders and

TABLE 4—Effects of Gun Ownership Level on Age-Adjusted Firearm Homicide Rate: United States, 1981–2010

Gun Ownership Level	IRR (95% CI)	P
Current gun ownership		
Full model[a]	1.008 (1.004, 1.012)	.001
Excluding states with missing data[b]	1.009 (1.005, 1.014)	.001
Restricted to years 2001, 2002, and 2004[c]	1.023 (1.014, 1.032)	.001
Survey measure of gun ownership used instead of proxy measure (years 2001, 2002, and 2004 only)[d]	1.016 (0.997, 1.036)	.1
Full model executed in SAS[e]	1.009 (1.004, 1.014)	.001
Variables with interpolated or extrapolated values omitted from analysis[f]	1.009 (1.005, 1.014)	.001
Control for temporal trends in homicide rates (linear and quadratic terms for time included in model)	1.010 (1.005, 1.014)	.001
Individual data points weighted by square root of state population	1.011 (1.005, 1.017)	.001
Poisson model instead of negative binomial model	1.008 (1.004, 1.013)	.001
Gun ownership in previous years		
Lagged 1 y	1.009 (1.005, 1.013)	.001
Lagged 2 y	1.005 (1.001, 1.009)	.024

Note. CI = confidence interval; IRR = incidence rate ratio.
[a]Included fixed effects for year, adjustment for clustering within states, and controls for percentage young (aged 15–29 y), percentage young males, percentage Black, percentage Hispanic, poverty, unemployment, household income, educational attainment, income inequality, level of urbanization, alcohol consumption, violent crime rate, nonviolent crime rate, hate crime rate, divorce rate, hunting licenses, region, age-adjusted nonfirearm homicide rate, incarceration rate, and suicide rate.
[b]Excluded data from states with missing data for age-adjusted firearm homicide rate in any year: New Hampshire, North Dakota, Vermont, Wyoming, Hawaii, and South Dakota.
[c]Years for which Behavioral Risk Factor Surveillance System (BRFSS) data on household gun ownership were available.
[d]Main predictor variable was proportion of households with guns according to BRFSS in 2001, 2002, and 2004; proxy measure (firearm suicides divided by all suicides) was not used in this model.
[e]Model run with PROC GENMOD in SAS version 9.1 (SAS Institute, Cary, NC), with empirical SEs.
[f]Variables with interpolated or extrapolated values were household income, educational attainment, income inequality, level of urbanization, hate crime rate, divorce rate, and incarceration rate.

was not sensitive to model specification. Our work expanded on previous studies not only by analyzing more recent data, but also by adjusting for clustering by year and state and controlling for factors, such as the rate of nonfirearm homicides, that likely capture unspecified variables that may be associated with both gun ownership levels and firearm homicide rates.

The correlation of gun ownership with firearm homicide rates was substantial. Results from our model showed that a 1-SD difference in the gun ownership proxy measure, FS/S, was associated with a 12.9% difference in firearm homicide rates. All other factors being equal, our model would predict that if the FS/S in Mississippi were 57.7% (the average for all states) instead of 76.8% (the highest of all states), its firearm homicide rate would be 17% lower. Because of our use of a proxy measure for gun ownership, we could not conclude that the magnitude of the association between actual household gun ownership rates and homicide rates was the same. However, in a model that incorporated only survey-derived measures of household gun ownership (for 2001, 2002, and 2004), we found that each 1-SD difference in gun ownership was associated with a 24.9% difference in firearm homicide rates.

Our results were consistent with, but generally lower than, previous estimates of the effect of gun ownership on homicide rates. We were able to replicate Miller et al.'s study by restricting our analysis to 1988 to 1997 and controlling for the same variables as they did. We obtained an IRR of 1.36 (95% CI = 1.20, 1.54) for the gun ownership proxy; their result was 1.41 (95% CI = 1.27, 1.57).[34] After adjusting for clustering by state with GEEs, incorporating year fixed effects, and including additional significant predictors, we obtained an IRR of 1.17 (95% CI = 1.11, 1.24).

Limitations

We used a proxy measure of firearm ownership that did not perfectly correlate with survey-derived measures and was therefore not ideal. We have 2 reasons for believing that the observed relationship between gun ownership and homicide rates was not an artifact of the use of this proxy measure. First, when we restricted the analysis to 2001, 2002, and 2004 and relied on a survey measure of gun ownership, the parameter estimate for gun ownership was similar to (but higher than) that obtained with the proxy measure. Second, the observed relationship between the proxy measure of gun ownership and homicide rates was specific to firearm homicides. We detected no significant relationship between gun ownership and nonfirearm homicide rates.

We conducted an ecological study with large aggregates (states) representing the units of analysis. This introduced the possibility that an unknown confounder could explain the observed relationship. For this to occur, a putative confounder would have to be strongly correlated with both gun ownership and firearm homicide rates, but not highly correlated with any of the other variables we measured. Because of the number of predictor variables we incorporated in our analysis, this seems unlikely. The likelihood was lessened further by our failure to find a significant relationship between gun ownership and nonfirearm homicide rates. Nevertheless, the possibility remains that an omitted variable confounded the observed relationship.

A reverse causal association was also possible. For example, increases in firearm homicide rates could have led to efforts by state residents to acquire guns, thus increasing gun ownership levels.[9,25,29,32,34–36,41,79,80] We addressed this question with a lagged variable and found that gun ownership, lagged by either 1 or 2 years, was still a significant predictor of firearm homicide rates. This is consistent with, but does not prove, the hypothesis that changes in gun ownership rates affect subsequent firearm homicide rates. It is not possible in a panel study such as ours to determine causality. Furthermore, although this was a panel study, the variation occurred mainly in the cross section, because the differences in firearm homicide across states were greater than the changes over time.

Conclusions

Our study substantially advances previous work by analyzing recent data, examining the longest and most comprehensive panel of state-specific data to date, and accounting for year and state clustering and for a wide range of potential confounders. We found a robust relationship between gun ownership and firearm homicide rates, a finding that held whether firearm ownership was assessed through a proxy or a survey measure, whether state clustering was accounted for by GEEs or by fixed effects, and whether or not gun ownership was lagged, by up to 2 years. The observed relationship was specific to firearm-related homicide. Although we could not determine causation, we found that states with higher levels of gun ownership had disproportionately large numbers of deaths from firearm-related homicides. ■

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Contributors

M. Siegel obtained and analyzed the data. All authors conceptualized and designed the study, interpreted the results, wrote the article, and critically reviewed and commented on the article.

Human Participant Protection

Institutional review board approval was not needed for this study because secondary data sources were used.

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