Firearm legislation and firearm mortality in the USA: a cross-sectional, state-level study

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Summary

Background In an effort to reduce firearm mortality rates in the USA, US states have enacted a range of firearm laws to either strengthen or deregulate the existing main federal gun control law, the Brady Law. We set out to determine the independent association of different firearm laws with overall firearm mortality, homicide firearm mortality, and suicide firearm mortality across all US states. We also projected the potential reduction of firearm mortality if the three most strongly associated firearm laws were enacted at the federal level.

Methods We constructed a cross-sectional, state-level dataset from Nov 1, 2014, to May 15, 2015, using counts of firearm-related deaths in each US state for the years 2008–10 (stratified by intent [homicide and suicide]) from the US Centers for Disease Control and Prevention's Web-based Injury Statistics Query and Reporting System, data about 25 firearm state laws implemented in 2009, and state-specific characteristics such as firearm ownership for 2013, firearm export rates, and non-firearm homicide rates for 2009, and unemployment rates for 2010. Our primary outcome measure was overall firearm-related mortality per 100 000 people in the USA in 2010. We used Poisson regression with robust variances to derive incidence rate ratios (IRRs) and 95% CIs.

Findings 31 672 firearm-related deaths occurred in 2010 in the USA (10·1 per 100 000 people; mean state-specific count 631·5 [SD 629·1]). Of 25 firearm laws, nine were associated with reduced firearm mortality, nine were associated with increased firearm mortality, and seven had an inconclusive association. After adjustment for relevant covariates, the three state laws most strongly associated with reduced overall firearm mortality were universal background checks for firearm purchase (multivariable IRR 0·39 [95% CI 0·23–0·67]; p=0·001), ammunition background checks (0·18 [0·09–0·36]; p<0·0001), and identification requirement for firearms (0·16 [0·09–0·29]; p<0·0001). Projected federal-level implementation of universal background checks for firearm purchase could reduce national firearm mortality from 10·35 to 4·46 deaths per 100 000 people, background checks for ammunition purchase could reduce it to 1·99 per 100 000, and firearm identification to 1·81 per 100 000.

Interpretation Very few of the existing state-specific firearm laws are associated with reduced firearm mortality, and this evidence underscores the importance of focusing on relevant and effective firearms legislation. Implementation of universal background checks for the purchase of firearms or ammunition, and firearm identification nationally could substantially reduce firearm mortality in the USA.

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Introduction

Firearm violence in the USA is an issue of substantial public health concern.[1] Mortality due to firearms is endemic, characterised by stable but high national fatality rates since 2000.[2] More than 90 people are killed every day by firearms in the USA.[3] This burden of fatal firearm injuries varies widely between states and by race or ethnic origin, with higher firearm mortality rates occurring among black people than white people.[2,3] Firearm mortality mainly occurs among young adults aged 17 to 25 years and accounts for 80% of all homicides and 45% of all suicides within this age group.[3,4]

Firearms are ubiquitous in the USA, and the high level of firearm ownership has been directly associated with an increased risk of firearm-related mortality.[5,6] Firearm violence prevention strategies have produced a small amount of success in the form of a federal law—the "Brady Handgun Violence Prevention Act" (enacted Nov 30, 1993)—often called the Brady Law.[7] The Brady Law requires background checks to be undertaken for individuals before they can purchase a firearm from a federally licensed dealer, manufacturer, or importer—unless an exception applies. However, the loopholes to this statute allow unfettered sales from unlicensed dealers. To offset the limitations of the Brady Law, several states have instituted separate laws intended to fill these gaps.[8,9] States have implemented firearm laws in an effort to reduce firearm access to children (child-access prevention [CAP] laws) and to regulate firearm storage practices.[10,11] Conversely, many states have also enacted laws aimed to further deregulate the carrying of firearms through so-called stand-your-ground laws (where an individual may use deadly force in self-defence without the duty to retreat when faced with a reasonable perceived threat).[10] These state regulations have been implemented either as amendments to an existing firearm law or as a separate legislation.

Some preliminary evidence exists regarding the effectiveness of the different state laws in reducing

Research in context

Evidence before this study
We searched PubMed with the terms "gun" OR "firearm", AND "policy" OR "law" OR "legislation" OR "legislature" OR "laws" OR "policies", for articles published in any language before May 1, 2015. We identified 1154 articles, of which 1008 remained after adding the restriction term "humans". Several articles assessed the effect of one or few firearm laws or policies, but we identified only six articles that studied the effect of several laws on firearm deaths in the USA, and only two that deemed all firearm laws as a score.

Added value of this study
Our findings showed that of the laws we surveyed, only a few were associated with reduced firearm mortality, whereas most were either associated with increased mortality or had no

conclusive association. We showed that federal-level implementation of the three most strongly associated laws—universal background checks for firearm purchase, background checks for ammunition, and requiring firearm identification by either microstamping or ballistic fingerprinting—would substantially reduce overall national firearm mortality.

Implications of all the available evidence
Implementation of background checks for firearm or ammunition purchase and firearm identification nationally could substantially reduce firearm mortality in the USA. However, very few of the existing state-specific firearm laws are associated with reduced firearm mortality, and this evidence underscores the importance of focusing on relevant and effective firearms legislation.

firearm mortality.[8,11,12] However, this evidence has focused on assessments of either the cumulative effect of several firearm laws or an arbitrary legislative strength score[1] and the effect of a select few laws such as stand-your-ground or CAP.[11,12] To our knowledge, no studies have assessed several firearm laws together with all relevant state-level characteristics. In view of the many firearm laws in different states, we aimed to build on the available evidence to determine the independent effect of different firearm laws on firearm mortality, taking into account relevant firearm laws and state-specific characteristics.

Methods
Study design
We did a cross-sectional, state-level study from Nov 1, 2014, to May 15, 2015, to assess the effect of different firearm legislation on firearm mortality in the USA, taking into account state-specific firearm legislation, unemployment, non-firearm homicides, firearm exports, and firearm ownership rates based on previous studies (appendix).[8,9,11,13] The Columbia University Ethics Review Board deemed the study exempt from federal regulations for the protection of human research participants.

Data sources
We obtained counts of firearm deaths in each US state from 2008 to 2010, both overall counts and stratified according to intent (homicide or suicide), from querying the restricted version of the US Centers for Disease Control and Prevention's Web-Based Injury Statistics Query and Reporting System (WISQARS).[3] We extracted counts of non-firearm homicide and overall firearm mortality counts and rates in each state during 2009. Mortality data in WISQARS is compiled by the National Center for Health Statistics using data from the death registry.

We obtained information about state-specific firearm related legislation for the year 2009 from the Brady Center to Prevent Gun Violence[14] and validated this information using the online academic research database LexisNexis Academic. Since 2007, the Brady Center has published annual reports about state-specific firearm legislature and an arbitrary legislative scorecard with specific scores for firearm legislative strength.[14] Because firearm legislation pivoted increasingly towards pro-firearm from 2009, we grounded our study in 2009 firearm legislation to assess the positive effects of firearm laws. Laws prohibiting firearms in the workplace or university campuses were present in most states and not used for this analysis.

We obtained the annual means for the employment status of the civilian, non-institutional population in 2010 from the US Bureau of Labor Statistics (BLS).[15] We used data from 2010, because many firearm fatalities are suicides, and suicides are associated with crucial incidents such as the loss of a job.[16] Annual data about employment and unemployment in the USA and subgroups within the USA are available from the Current Population Survey (CPS) and the Local Area Unemployment Statistics (LAUS) programme.[17,18] The CPS is undertaken by the US Census Bureau for the BLS and samples about 50 000 households,[17] and LAUS is a federal-state cooperative programme in participation with state employment security agencies.[18] We obtained firearm export data for each state from the US Bureau of Alcohol, Tobacco, Firearms and explosives (ATF), US Department of Justice.[19] The ATF traces firearms on behalf of thousands of federal, state, local, and foreign law-enforcement agencies, and prepares state-by-state reports using trace data, which are intended to provide the public with insight into firearms recoveries. We assessed firearm ownership using data from a survey by an internet-based market research company (YouGov) of individuals older than 18 years in the USA in 2013.[13] We used the most recent firearm ownership data from 2013, because the last available data in each state were for 2004 and firearm ownership rates are reported to have fallen.

All firearm legislation data are in table 1 and the appendix. We classified the annual means for 2010 state-specific employment status,[15] firearm export rate of crime guns (ie, a gun that has been used to commit a crime) for each state in 2009,[19] firearm ownership in different states in 2013[13] and non-firearm homicide rates in 2009 per 100 000 people[3] into four groups by quartiles. Details of covariates are also presented in the appendix.

Outcomes

Our primary outcome measure was overall firearm-related mortality per 100 000 people in 2010. Secondary outcomes were firearm-related homicides and suicides per 100 000 in 2010. We determined the independent association of different firearm laws with overall firearm mortality, and with firearm-related homicide and suicides separately, taking into account relevant firearm laws and state-specific characteristics. We also projected the potential reduction of firearm mortality rates if the three firearm laws with the strongest association were enacted at the federal level.

Statistical analysis

First, we assessed the distribution of the total counts of firearm-related mortality in 2010 in the USA. Because the variance of our outcome was equal to the mean, we used Poisson regression with population as an offset to normalise population sizes, and robust standard

	Description	States with laws
Firearm dealer regulations		
Gun dealer licence	State licence required for gun dealers	AL, CA, CT, DE, GA, HI, IN, MD, MA, NH, NJ, NY, PA, RI, SC, VA, WA
Record keeping and retention	Gun dealers are required to keep and retain records	AL, CA, CO, CT, DE, GA, IL, ME, MD, MA, MI, MS, NJ, NY, NC, OR, PA, RI, TN, VT, VA, WA, WI, WY
Report records to state	Gun dealers are required to report records to state for retention	AL, CA, CT, MD, MA, MI, NJ, NY, OR, PA, WA
Mandatory theft reporting	Gun dealers are required to report firearm theft	CA, MA, NJ, OH
Gun store security precaution	Gun dealers are required to have at least one store security precaution	AL, CA, DE, MA, MN, NJ, PA, RI, SC, VA, WA
Police inspection	Inspections of gun stores are allowed	AL, CA, CO, CT, DE, GA, HI, IL, ME, MA, MI, MN, MS, NJ, NY, NC, OR, RI, SC, TN, VT, VA, WY
Owner purchase regulations		
Bulk purchases limitation	Handgun purchases are limited to one per month with or without one or more exceptions	Carries the law with exceptions: VA; carries the law with no exceptions: CA, MD, NJ
Ballistic fingerprinting or microstamping of semi-automatic handguns (firearm identification)	Firearms can be identified by ballistic fingerprinting Microstamping is required on semi-automatic handguns	MD, NY, CA
Owner theft reporting	Firearm owners are required to report lost or stolen guns	CT, MA, MI, NJ, NY, OH, RI
Background checks or additions		
Universal background check	Required for all firearms or handguns only	Handguns only: CT, HI, MD, NJ, PA; all firearms: CA, RI
Fingerprinting	Fingerprinting is required to purchase firearms	CA, CT, HI, MA, MI, NJ, NY
Safety training	Safety training or testing is required to purchase firearms	CA, CT, HI, MA, MI, RI
Extension of background-check limit	The 3-day limit for background checks can be extended	CA, CT, HI, MD, MA, MN, NJ, NY, NC, RI, WA
Permit law involvement	The permit process involves law enforcement (ie, the local police force)	CT, HI, IA, MA, MI, MN, NJ, NY, NC
Closure of gun show loophole	Laws enforcing background checks or permits for purchase of all firearms, handguns, or long guns (states with universal background checks on all firearms are not eligible for the gun show loophole)	Permit for long guns, but no background check per purchase required: HI, NJ; permit for handguns, but no background check per purchase required: IA, MI, NC; permit for all firearms, but no background check per purchase required: MA; background check on long guns only for each purchase: CT; background check on handguns only for each purchase: none; background check on all firearms for each purchase: CO, IL, NY, OR
Ammunition purchaser records	Ammunition purchaser records are kept or vendor licence is required	CA, MD, MA, WA
Ammunition Brady check	Ammunition Brady check or permit is required to purchase ammunition	IL, MA, NJ
Child access prevention laws		
Integrated locks	Integrated locks are sold on all handguns	MD
External locks	External locks are sold with all handguns	CA, CT, IL, MD, MA, MI, NJ, NY, PA, RI
Standards for locks	Standards are present on all external locks	CA, MD, MA, NY
Child handgun restrictions	Only authorised users ≥16 years are able to operate new handguns	NJ
Child access prevention	Age restrictions are set for use of firearms	13 years and younger: IL, IA, MT, VA, WI; 14 or 15 years and younger: CT, FL, HI, ME, MD, NH, NJ, RI; 16 or 17 and younger: CA, DE, KS, MA, MN, NV, NC, TX
Juvenile handgun purchases	Must be aged at least 21 years to purchase firearms	CA, CT, DE, HI, IL, IA, MD, MA, NE, NJ, NY, OH, RI, WA
		(Table 1 continues on next page)

	Description	States with laws
(Continued from previous page)		
Ban on specific weapons		
Assault weapons ban (eg, semi-automatic rifles and pistols)	Bans or restrictions are placed on assault weapons; the determination of ban depends on the presence of a specific number of features	Two feature test on assault pistols only: HI, ND; two feature test: CT, MA, NY; one feature test: CA, NJ
Large magazine ban	Bans placed on a specific number of rounds	15 rounds or fewer: NJ; ten rounds or fewer: CA, HI, MA, NY
Public place restrictions		
Workplace restriction*	Employers are not forced to allow firearms in parking lots	AL, AR, CA, CO, CT, DE, HI, IL, IN, IA, ME, MD, MA, MI, MO, NE, NV, NH, NJ, NM, NY, NC, ND, OH, OK, OR, PA, RI, SC, TN, TX, VT, VA, WA, WV, WI, WY
Campus restriction*	Colleges are not forced to allow firearms on campus	AL, AK, AZ, AR, CA, CO, CT, DE, FL, GA, HI, ID, IL, IN, IA, KS, KY, LA, ME, MD, MA, MI, MN, MS, MO, MT, NE, NV, NH, NJ, NM, NY, NC, ND, OH, OK, OR, PA, RI, SC, SD, TN, TX, VT, WA, WV, WI, WY
Carrying concealed weapons (CCW)	Law enforcement discretion is permitted in these states when issuing CCW permits	AL, CA, CT, DE, HI, IL, IA, MD, MA, NJ, NY, RI, WI, WY
Stand-your-ground	Laws that remove the traditional "duty to retreat" from an area outside the home or before the use of deadly force in self-defence	AL, AK, AR, FL, GA, IN, KS, KY, LA, MI, MS, MO, MT, NV, OH, OK, OR, SC, SD, TN, TX, UT, WV

AL=Alabama. CA=California. CT=Connecticut. DE=Delaware. GA=Georgia. HI=Hawaii. IN=Indiana. MD=Maryland. MA=Massachusetts. NH=New Hampshire. NJ=New Jersey. NY=New York. PA=Pennsylvania. RI=Rhode Island. SC=South Carolina. VA=Virginia. WA=Washington. CO=Colorado. IL=Illinois. ME=Maine. MI=Michigan. MS=Mississippi. NC=North Carolina. OR=Oregon. TN=Tennessee. VT=Vermont. WI=Wisconsin. WY=Wyoming. OH=Ohio. MN=Minnesota. IA=Iowa. MT=Montana. FL=Florida. KS=Kansas. NV=Nevada. TX=Texas. NE=Nebraska. ND=North Dakota. AR=Arkansas. IN=Indiana. MO=Missouri. NM=New Mexico. OK=Oklahoma. WV=West Virginia. AK=Alaska. AZ=Arizona. ID=Idaho. KY=Kentucky. LA=Louisiana. SC=South Carolina. SD=South Dakota. UT=Utah. *Data for these laws were not used in the analysis because of an absence of heterogeneity between states. For a full explanation of all laws, see appendix.

Table 1: Firearm legislation during 2009

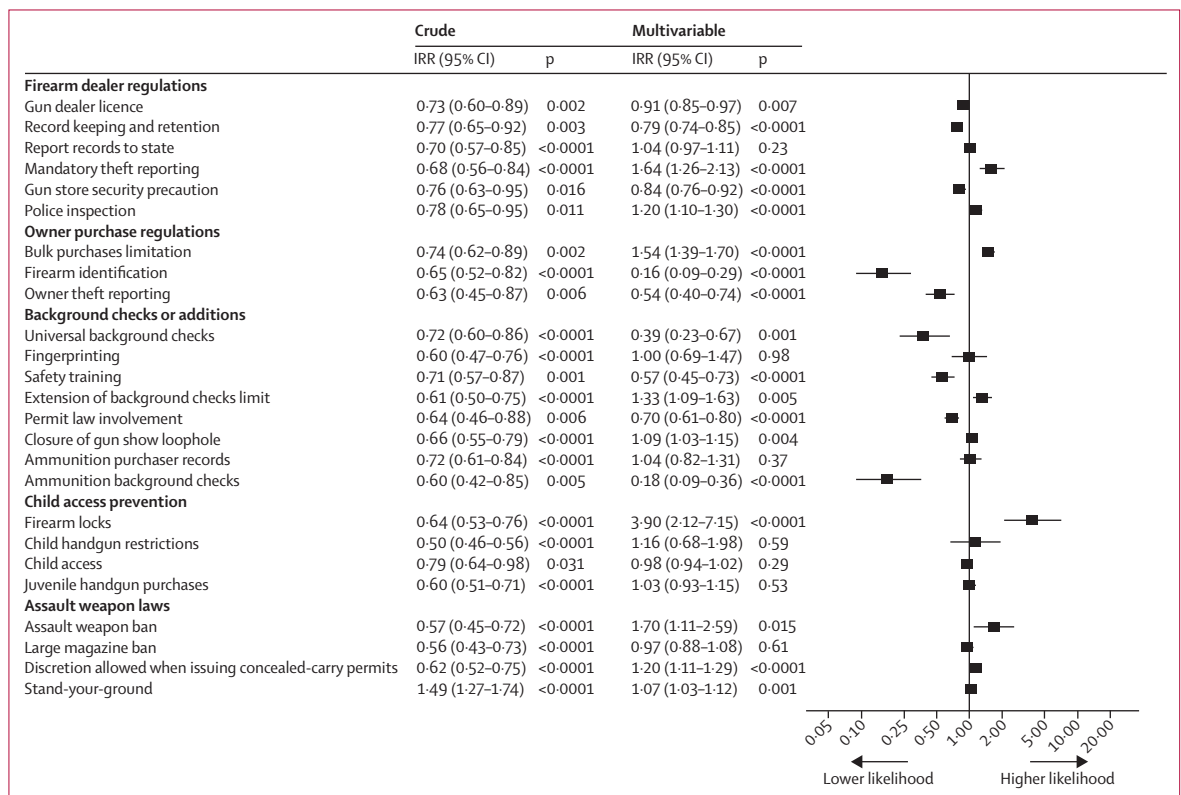*Figure:* Association of firearm laws with firearm-related deaths in 2009
IRR=incidence rate ratio.

errors.[20] We undertook crude and multivariable Poisson regression to estimate how the presence of a specific law corresponded to rates of firearm mortality in the US states and derived the incidence rate ratios (IRRs), 95% CI, and corresponding p values. We assessed model fit using deviance goodness-of-fit, McFadden's

adjusted R², and Akaike Information Criteria (statistics in appendix).[21] Second, from the final model, we predicted the probabilities for firearm mortality occurring in each state. Third, using the firearm risk profile for each state, we predicted the relative risk as of 2009 and then the relative risk if the states passed each of the effective firearm laws. Fourth, we predicted the possible discrete change in firearm mortality associated with federal level implementation of three most effective laws. Fifth, we did a sensitivity analysis using the change in firearm mortality rate per 100 000 people from 2008 to 2010 as the outcome. We also assessed the effectiveness of laws after combining them into different classifications, while keeping stand-your-ground and restrictions of so-called concealed-carry laws as separate laws (concealed-carry laws permit the carrying of a concealed weapon). Sixth, we used crude and multivariable models to determine the effectiveness of each firearm law separately for firearm homicides and suicides. We used Stata 13.1 to manage the data and do the analyses. All statistical tests were two-sided.

Role of the funding source

There was no funding source for this study. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

31 672 firearm-related deaths occurred in 2010 (10·1 per 100 000) in the USA, with a mean state-specific count of 631·5 events (SD 629·1). Analysed by state, Hawaii had

	Alaska		Florida		California		New York	
	COV	IRR (95% CI)	COV	IRR (95% CI)	COV	IRR (95% CI)	COV	IRR (95% CI)
Firearm ownership rate quartile*	4th	..	3rd	..	1st	..	1st	..
Unemployment rate quartile	2nd	..	4th	..	4th	..	2nd	..
Non-firearm homicide rate quartile	4th	..	3rd	..	3rd	..	3rd	..
Firearm export rate quartile	4th	..	1st	..	1st	..	1st	..
Firearm laws								
Gun dealer licence	..	0·91 (0·86–0·98)	..	1·91 (1·66–2·19)	Yes	..	Yes	..
Record keeping and retention	..	0·79 (0·74–0·85)	..	1·66 (1·47–1·88)	Yes	..	Yes	..
Report records to state	..	..	..	..	Yes	..	Yes	..
Mandatory theft reporting	..	..	..	..	Yes	..	..	..
Gun store security precaution	..	0·84 (0·76–0·92)	..	1·75 (1·54–1·98)	Yes	..	..	0·75 (0·66–0·85)
Police inspection	..	..	..	..	Yes	..	Yes	..
Bulk purchases limitation	..	..	..	..	Yes	..	..	..
Firearm identification	..	0·16 (0·09–0·29)	..	0·34 (0·20–0·56)	Yes	..	Yes	..
Owner theft reporting	..	0·54 (0·40–0·74)	..	1·14 (0·89–1·46)	..	0·74 (0·58–0·94)	Yes	..
Universal background check	..	0·39 (0·23–0·67)	..	0·81 (0·51–1·29)	Yes	..	..	0·35 (0·22–0·55)
Fingerprinting	..	..	..	..	Yes	..	Yes	..
Safety training	..	0·57 (0·45–0·73)	..	1·20 (0·86–1·67)	Yes	..	..	0·52 (0·37–0·72)
Extension of background-check limit	..	..	..	..	Yes	..	Yes	..
Permit law involvement	..	0·70 (0·61–0·80)	..	1·46 (1·27–1·67)	..	0·95 (0·83–1·08)	Yes	..
Closure of gun show loophole	..	..	..	..	Yes	..	Yes	..
Ammunition purchaser records	..	..	..	..	Yes	..	..	..
Ammunition background check	..	0·18 (0·09–0·36)	..	0·37 (0·20–0·69)	..	0·24 (0·13–0·45)	..	0·16 (0·09–0·30)
Firearm locks	..	..	..	..	Yes	..	Yes	..
Child handgun restrictions	..	..	..	..	..	..	..	..
Child access not permitted	..	..	Yes	..	Yes	..	..	..
Juveniles not permitted to purchase handguns	..	..	..	..	Yes	..	Yes	..
Assault weapon ban	..	..	..	..	Yes	..	Yes	..
Large magazine ban	..	..	..	..	Yes	..	Yes	..
Discretion allowed when issuing permits to carry a concealed weapon	..	..	..	..	Yes	..	Yes	..
Stand-your-ground	Yes	..	Yes	..	..	..	..	..

Data are predicted relative risk of firearm death associated with protective firearm laws in the presence of each protective law. For a description of the laws, see table 1. IRR=incidence rate ratio. COV=covariates used in the model. *Ownership rates from 2013, approximation for 2009 rates. IRR (95% CI) derived from Poisson regression with population of 2010 offset by adding each law separately in the +1 column. Homicide rates exclude firearm homicides. Data adjusted for unemployment, non-firearm homicide, firearm ownership, firearm export, and 2009 firearm mortality.

Table 2: **Risk of firearm death associated with protective firearm laws in four US states in 2010**

the lowest rate (n=45; 3·31 per 100 000) and Alaska had the highest (n=144; 20·3 per 100 000). 25 laws existed in 2009 that either controlled firearms or were permissive.

The figure shows the crude and adjusted analysis to assess the independent effect of each firearm law on firearm-related deaths. Predicted probabilities of firearm deaths in 2010 in each state are presented in the appendix. After adjustment for covariates, nine laws were associated with a reduced likelihood of firearm-related deaths, nine were associated with an increased likelihood, and seven laws did not have a significant association (figure). The nine control laws associated with reduced firearm mortality were state licence to sell firearms, keeping and retaining of sales records, at least one store security precaution, firearm identification, reporting of lost or stolen firearms, universal background checks for all firearms, safety training or testing requirement to purchase firearms, law enforcement involvement in obtaining of permits, and background checks for the purchase of ammunition.

The nine laws associated with an increase in the risk of firearm-related deaths were a requirement for the dealer to report records to the state for retention, allowing police inspection of stores, limiting the number of firearms purchased, a 3-day limit for a background-checks extension, background checks or permits during gun shows in states without universal background-check requirement (ie, closure of the gun show loophole), integrated or external or standard locks on firearms, a ban or restrictions placed on assault weapons, law enforcement discretion permitted when issuing concealed-carry permits, and stand-your-ground.

In 2009, of four analysed states (Alaska, Florida, California, and New York), Alaska had only stand-your-ground (a permissive law), low unemployment, and the highest rates of firearm ownership, non-firearm homicide, and export, with an overall firearm mortality rate in 2009 of 14·9 per 100 000 people (table 2). Using the 2009 data and the overall firearm mortality rate of 20·27 per 100 000 people in 2010, the predicted IRR was 2·74 (95% CI 2·29–3·30).

	Final model	Universal background checks	Ammunition background checks	Both types of background checks	Firearm identification	All three laws
Gun dealer licence	–0·91	–0·39	–0·18	–0·08	–0·16	–0·01
Record keeping and retention	–2·37	–1·02	–0·46	–0·20	–0·41	–0·04
Report records to state	0·44	0·19	0·08	0·04	0·08	0·01
Mandatory theft reporting	6·40	2·76	1·23	0·55	1·12	0·10
Gun store security precaution	–1·77	–0·76	–0·34	–0·15	–0·31	–0·03
Police inspection	1·87	0·81	0·36	0·16	0·33	0·03
Bulk purchases limitation	5·37	2·31	1·03	0·46	0·94	0·08
Firearm identification	–9·68	–4·17	–1·86	–0·83	–9·37	–0·83
Owner theft reporting	–5·13	–2·21	–0·99	–0·44	–0·90	–0·08
Universal background checks	–7·20	–6·98	–1·38	–1·38	–1·26	–0·25
Fingerprinting	0·05	0·02	0·01	0·00	0·01	0·00
Safety training	–4·71	–2·03	–0·91	–0·40	–0·82	–0·07
Extension of background-check limit	3·23	1·39	0·62	0·28	0·56	0·05
Permit law involvement	–3·35	–1·44	–0·64	–0·29	–0·59	–0·05
Closure of gun show loophole	0·88	0·38	0·17	0·08	0·15	0·01
Ammunition purchaser records	0·36	0·16	0·07	0·03	0·06	0·01
Ammunition background checks	–9·42	–4·06	–9·12	–4·06	–1·65	–0·73
Firearm locks	22·83	9·84	4·39	1·95	3·99	0·35
Child handgun restrictions	1·62	0·70	0·31	0·14	0·28	0·03
Child access not permitted	–0·22	–0·10	–0·04	–0·02	–0·04	0·00
Juvenile handgun purchases	0·36	0·15	0·07	0·03	0·06	0·01
Assault weapon ban	6·68	2·88	1·28	0·57	1·17	0·10
Large magazine ban	–0·28	–0·12	–0·05	–0·02	–0·05	0·00
Discretion allowed when issuing permits to carry a concealed weapon	1·92	0·83	0·37	0·16	0·34	0·03
Stand-your-ground	0·74	0·32	0·14	0·06	0·13	0·01
National rate	10·35	4·46	1·99	0·88	1·81	0·16

Data are discrete changes in firearm mortality per 100 000 people for each law after changes in the three most effective laws at a federal level. For a description of each law, see table 1. The model used is from the figure and firearm mortality rate in 2009 is held at 10·22 per 100 000 people (except for final model, which used 10·35 per 100 000 people) and the other covariates at their mean in all scenarios. These states are not entirely representative of all US states; we represent the diverse firearm risk profiles here. For the other state profiles, see appendix.

Table 3: Change in national firearm mortality per 100 000 people with federal implementation of the three most effective firearm laws

Predicted firearm mortality risk would be reduced the most with laws for firearm identification (by 84%), universal background checks (by 61%), and ammunition background checks (by 82%). In 2009, Florida had stand-your-ground and CAP laws, and an overall firearm mortality of 12·5 per 100 000 people. In 2010, the overall mortality was 12·06 per 100 000 people (IRR 2·09 [95% CI 1·84–2·37]), and predicted risk of firearm mortality would be reduced the most by firearm identification (by 66%) and ammunition background-check laws (by 63%). In 2009, California had 20 firearm laws (seven associated with reduced mortality, eight associated with increased mortality, and five inconclusive), and overall mortality of 8·37 per 100 000 people. In 2010, overall mortality was 7·88 per 100 000 (IRR 1·36 [95% CI 1·20–1·54]); predicted risk of firearm mortality would be reduced the most by laws implementing owner theft reporting (by 26%) and ammunition background checks (by 76%). New York had 15 firearm laws in 2009 (five associated with reduced mortality, six associated with increased mortality, and four inconclusive), and an overall firearm mortality of 4·96 per 100 000 people. Overall mortality in 2010 was 5·22 per 100 000 people (IRR 0·90 [95% CI 0·79–1·01]), and the laws that would reduce predicted firearm mortality risk the most were universal background checks (by 65%) and ammunition background checks (by 84%; data for the remaining 46 states are in the appendix).

Table 3 presents the change in national firearm mortality rate with federal-level implementation of the three firearm laws most strongly associated with reduced mortality. With 2009 overall firearm mortality at the national rate, if a law for universal background checks was implemented federally, overall firearm mortality could reduce from 10·35 to 4·46 per 100 000 (57% reduction). Similarly, in the presence of federal ammunition background checks, overall firearm mortality could decrease to 1·99 per 100 000 (81% reduction), and with firearm identification requirements to 1·81 per 100 000 (83% reduction). On the basis of our model, federal implementation of all three laws could reduce national overall firearm mortality to 0·16 per 100 000.

When the results of the adjusted analysis were stratified for homicide and suicide, they showed that six laws were associated with a significant reduction in firearm-related homicide deaths, the largest reduction with background checks for ammunition and firearm identification (table 4). Five laws were associated with increased homicide deaths and 14 had inconclusive associations. Firearm identification and permit processes involving law enforcement were associated with reductions in firearm-related suicide deaths, but three laws were associated with an increase and the remaining 20 were inconclusively associated.

Results of the sensitivity analyses of effectiveness of firearm law classifications on overall, homicide, and suicide firearm-related deaths, and firearm laws on the change in firearm-related mortality rate from 2008 to 2010, were similar to the main findings (appendix).

	Homicide		Suicide	
	IRR (95% CI)	p value	IRR (95% CI)	p value
Firearm dealer regulations				
Gun dealer licence	0·96 (0·81–1·14)	0·63	0·91 (0·83–1·00)	0·054
Record keeping or retention	0·82 (0·60–1·10)	0·19	0·93 (0·81–1·08)	0·35
Report records to state	0·65 (0·53–0·81)	<0·0001	1·09 (0·98–1·21)	0·094
Mandatory theft reporting	2·16 (1·26–3·68)	0·005	1·30 (0·94–1·80)	0·12
Gun store security precaution	0·95 (0·72–1·26)	0·73	0·95 (0·81–1·12)	0·55
Police inspection	1·12 (0·86–1·46)	0·40	1·01 (0·87–1·17)	0·91
Owner purchase regulations				
Bulk purchases limitation	1·81 (1·26–2·59)	0·001	1·30 (1·11–1·52)	0·001
Firearm identification	0·07 (0·02–0·29)	<0·0001	0·42 (0·19–0·95)	0·036
Owner theft reporting	0·42 (0·21–0·82)	0·011	0·74 (0·51–1·07)	0·34
Background checks or additions				
Universal background checks	0·21 (0·07–0·63)	0·006	0·72 (0·37–1·40)	0·34
Fingerprinting	0·68 (0·30–1·58)	0·37	1·20 (0·73–1·97)	0·47
Safety training	0·56 (0·27–1·15)	0·11	0·72 (0·48–1·07)	0·11
Extension of background-checks limit	1·50 (0·99–2·27)	0·057	1·09 (0·86–1·39)	0·48
Permit law involvement	0·86 (0·68–1·09)	0·21	0·81 (0·69–0·96)	0·015
Closure of gun show loophole	0·85 (0·71–1·01)	0·066	1·17 (1·09–1·27)	<0·0001
Ammunition purchaser records	0·96 (0·51–1·82)	0·90	1·04 (0·73–1·49)	0·82
Ammunition background checks	0·07 (0·02–0·33)	0·001	0·44 (0·18–1·08)	0·074
Child access prevention				
Firearm locks	10·9 (2·95–40·6)	<0·0001	1·45 (0·68–3·09)	0·34
Child handgun restrictions	1·86 (0·57–6·03)	0·30	0·77 (0·39–1·51)	0·45
Child access	0·83 (0·73–0·94)	0·004	1·00 (0·94–1·06)	0·99
Juvenile handgun purchases	0·92 (0·71–1·20)	0·54	1·01 (0·88–1·16)	0·92
Assault weapon laws				
Assault weapon ban	2·83 (1·30–6·20)	0·009	1·11 (0·67–1·85)	0·68
Large magazine ban	1·08 (0·69–1·70)	0·72	0·90 (0·73–1·10)	0·29
Discretion can be used with carrying concealed weapons law	1·83 (1·45–2·32)	<0·0001	0·98 (0·86–1·12)	0·76
Stand-your-ground	0·99 (0·85–1·16)	0·92	1·09 (1·03–1·15)	<0·0001

For details of laws, see table 1. IRR (95% CI) and p values derived from Poisson regression with population of 2010 as offset. Homicide rates exclude firearm homicides. Homicide model is adjusted for unemployment, non-firearm homicides, firearm ownership, firearm exports, and 2009 firearm homicide mortality rate. Suicide model is adjusted for unemployment, non-firearm homicides, firearm ownership, firearm exports, and 2009 firearm suicide mortality rate. IRR=incidence rate ratio.

Table 4: **Firearm legislation in 2009 and the risk of fatal firearm homicides and suicides**

Discussion

Using a comprehensive dataset including all state-specific firearm laws, we showed nine laws to be associated with reduced overall firearm mortality, nine to be associated with increased mortality, and seven to be inconclusive. The three laws most strongly associated with reduced firearm mortality were universal background checks for firearm purchase, background checks for ammunition, and requiring firearm identification by either microstamping or ballistic finger-printing. We showed that federal-level implementation of these three laws would substantially reduce overall national firearm mortality. Finally, the three laws most strongly associated with reduced homicide-specific firearm mortality were universal background checks for

firearm purchase, background checks for ammunition, and firearm identification; firearm identification was associated with reduced suicide-specific firearm mortality.

The nine laws associated with reduced firearm mortality were in line with evidence from national and international studies that established the protective effect of firearm control policies.[8,9,11,22] Legislation regarding background checks for firearm and ammunition purchase was the most effective legislation identified in our study, similar to another cross-sectional study showing the protective effect by those laws that strengthened the federal Brady Law.[8] The major flaw in the Brady Law allows private owners, gun shows, and unlicensed dealers to transfer firearms freely, even to people prohibited from owning firearms.[23] Together with laws to strengthen background checks, we identified three effective firearm dealer regulations, which was by contrast with results in a cross-sectional study[8] that suggested all firearm laws that curb trafficking to be inconclusive. The inconclusive effect in this earlier study could be due to a pooled class containing all dealer and owner regulatory laws, whereas our study considered the laws individually under separate classifications. Another cross-sectional study[9] assessing the effect of state regulations showed similar results to our study for which individual laws were either effective or ineffective, specifically the effect of state-licence requirements needed for dealers to sell firearms.

In this study, which assessed the effect of firearm regulatory laws on firearm homicides, state licensing and authorised inspections were associated with lower homicide rates, but record keeping did not reduce homicides. The results of our analysis suggests that CAP laws are ineffective, which are in line with conflicting results on the effect of CAP laws available up to now.[8,11] In a nationally representative study that used Brady legislative score,[12] a protective effect of CAP laws was shown with a differential according to firearm storage characteristics. By contrast, we showed that requirements for firearm locks, one of the CAP laws, to be ineffective, which was similar to the null effect reported in a study[8] assessing the effect of firearm dealer regulations on firearm homicides. On one hand, the increased risk attributed to firearm locks in our study could be explained by the results of a longitudinal study[20] for which presence of CAP laws was associated with an increased likelihood of unsafe firearm storage in states with fewer firearm policies. On the other hand, we showed the permissive stand-your-ground law to be associated with an increased risk in firearm mortality, which was similar to the results of another analysis[10] in which stand-your-ground was associated with an increase in accidental firearm injuries.

After establishing the independent association of each firearm law with mortality on the basis of 2009 state firearm policies and related characteristics and 2010 firearm mortality per 100 000 people in each state, we predicted the effect of nine most strongly associated laws

in each of the 50 states and the magnitude of reduction in firearm mortality rates. Strengthening the Brady Law[7] by universal background checks for firearms and ammunition was shown to be the most effective legislation along with firearm identification, a firearm owner regulation. Our projected decrease related to comprehensive background checks was in line with the scientific evidence and the scientific support for passing this crucial legislation.[11,24,25] On a national level, our projected rates of reduction in firearm mortality directly address the main recommendation by an inter-disciplinary, interprofessional group of leaders of national health professional organisations and the American Bar Association.[26]

Our finding that the three laws most strongly associated with reduced homicide firearm mortality were expansion of background checks for all firearm and ammunition purchases and firearm identification, was analogous to the results by a few state panel studies that assessed the effect on overall and intent-specific firearm mortality.[8,25,27] Our results also substantiate the findings by a state-level study[5] that examined the effects of the differences among states in the background checks required for firearm purchase and reported that doing local-level background checks was associated with a 22% lower homicide rate from 2002 to 2004.

Several limitations should be considered when interpreting our findings. The main limitation is that our study design used state characteristics in 2009 and the outcome of firearm mortality rates in 2010, without considering the range of changes and duration of the firearm laws in place. Assessment of the effect of legislative policies is akin to assessment of the effect of natural experiments or real-world data. We expect the fall in mortality to be a long-term effect and might take years to occur.

Several confounding social and state-level factors and firearm laws act both before and after the respective laws; therefore, some residual confounding might be present. Because data for state-specific firearm ownership are not available, we used ownership data from 2013 as an approximation because we identified no difference in national data between 2004 and 2013.[28] However, we recognise that state-level differences and the direction of the error cannot be assessed. We were unable to obtain state-level estimates of firearm storage practices to be used as a covariate. Most firearm deaths are either homicide or suicide, with a small proportion of unintentional deaths that are directly related to unsafe storage practices. Some of the firearm laws that were intended to reduce firearm violence did not show any conclusive association; and this could be either a true non-association or a result from chance or not having sufficient duration after implementation to show true association. We have not included suicide-prevention programmes in our model because of wide variation in the setting of such programmes. Variation in

suicide-prevention programmes (implementation and effectiveness) across different states might also contribute to some residual confounding.

In conclusion, we showed an overall strong benefit of comprehensive background-check laws for firearm and ammunition purchases and firearm identification laws to effectively reduce firearm mortality, but also showed that the stand-your-ground law was associated with a significant increase in firearm mortality. Implementation of background checks was associated with a reduction in firearm-related homicides and firearm identification laws decreased firearm-related suicides. Only some of the existing state-specific firearm laws are associated with reduced firearm mortality, underscoring the importance of focus on relevant and effective legislation.

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