Difference-in-differences analysis of age of handgun sales policies and adolescent suicide fatalities

Julia Raifman, ScD
Boston University School of Public Health

Elysia Larson, ScD
Harvard T.H. Chan School of Public Health

Michael Siegel, MD, MPH
Boston University School of Public Health

Michael Ulrich, JD, MPH
Boston University School of Public Health

Colleen L. Barry, PhD
Johns Hopkins Bloomberg School of Public Health

Anita Knopov, BA
Boston University School of Public Health

Sandro Galea, MD, DrPH
Boston University School of Public Health

Corresponding author:
Julia Raifman, ScD
Department of Health Law, Policy, and Management
Boston University School of Public Health
Talbot Building
715 Albany Street
Boston, MA 02118
jraifman@bu.edu
Phone: 919-593-0738

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Abstract

Background: Suicide is the second leading cause of death among adolescents.

Objective: Evaluate association between state policies limiting handgun sales to those over 21 years and adolescent suicide.

Design: We compared aged 18-20 suicide fatality rates before and after policy changes in three states that changed the age of handgun sales relative to neighboring states that did not change policies using a difference-in-differences approach.

Setting: Missouri, South Carolina, West Virginia implemented policy changes in 2007, 2008, and 2010, respectively. We used data from five years before and after policy changes and compared each state to neighboring states.

Participants: All adolescents aged 18 to 20 years old in the nine study states.

Intervention: State policy requiring unlicensed handgun sales be limited to individuals aged 21 or older.

Measurements: Suicide fatality rate, controlling for state, year, proportion of adult suicides due to firearms, and state poverty and unemployment levels.

Results: Age 21 handgun sales policies were associated with 2.7 fewer suicide fatalities per 100,000 person-years (95% confidence interval [CI]: -4.1 to -1.4, permutation adjusted p-value = 0.02) among adolescents aged 18 to 20 years old. They were associated with reduced firearm suicide fatalities (-2.3, 95% CI: -3.6 to -1.0) but not non-firearm suicide fatalities (-0.5, 95% CI: -2.0 to 1.0). The 22% (95% CI: 7% to

36%) relative reduction in overall suicide fatalities would be equivalent to 249 (95% CI: 77 to 420) fewer suicide fatalities each year in the 35 US states without age 21 handgun sales policies.

Limitations: Suicide is a rare outcome and generalizability may be limited.

Conclusions: Age 21 handgun sales state policies were associated with reduced adolescent suicide fatalities.

Introduction

There were more than 47,000 suicide fatalities in 2017, marking an increase in the suicide fatality rate in the United States (US) for the tenth year in a row overall and among adolescents (1). Suicide is a particular concern for adolescents, as the second most common cause of adolescent death (2). Firearms account for more than half of US suicide fatalities (3). With increased attention to the role of firearms in adolescent fatalities in the wake of the Marjory Stoneman Douglas High School shooting, Vermont and Florida passed bills limiting firearm sales to those 21 years or older in 2018 (4,5). We investigated the relationship between age of firearm purchase policies and adolescent suicide fatalities.

Firearms are prevalent in American households, with 41% of Americans reporting living in a household with a gun in 2017 (6). Firearms are a particularly lethal method of suicide (7), and greater access to firearms is associated with increased suicide fatalities. Each 10% increase in state-level household firearm ownership was associated with 2.4 more suicide fatalities per 100,000 young adults aged 18 to 29 years (8). Each 10% reduction in household firearm ownership between 1981 and 2002 was associated with an 8.3% reduction in suicide fatalities among children younger than 20 years (9). Firearms purchases are specifically related to suicide, with the risk of suicide by firearms 57 times greater in the week following handgun purchase (10).

A 1968 federal law required that licensed firearms dealers only sell handguns to those aged 21 or older, but did not impose an age limit on unlicensed sales. Since the Brady Handgun Violence Prevention Act was implemented in 1994 (11), the minimum age of firearm sales across the country has been 18 years for all firearm sales. In 2018, 15 states have policies requiring unlicensed handgun sales be limited to purchasers aged 21 or older; the other 35 states continue to permit unlicensed sales to those aged 18 to 20 years (12). Federal policy permits firearms sellers to be unlicensed if they do not regularly sell firearms for profit, without specifically defining regular sales (13).

There is little evidence on whether policies limiting handgun sales to older ages are associated with suicide fatalities, particularly since the 1994 Brady Act. A prior study evaluated the link between suicides and minimum purchase age laws passed in 29 states between 1976 and 2001, finding that age 21 handgun sales policies were associated with significant reductions in firearm suicides but not overall suicides, suggesting that there could have been means replacement of firearms with non-firearms (14). The prior study was based on difference-in-differences design but did not examine pre-period trends in all-cause suicide fatalities to assess the suitability of the comparison group.

Aiming to provide evidence most relevant to the current policy environment, and with a difference-in-differences analysis satisfying the parallel trends assumption, we estimated the effects of the minimum firearm purchase age in the 3 states with policy changes over the past 15 years. The states that changed their age of handgun purchase policies were Missouri, South Carolina, and West Virginia, which implemented changes in 2007, 2008, and 2010, respectively.

Methods

Overview

To evaluate the relationship between age 21 handgun sales policies and adolescent suicide fatalities, we used data from Center for Disease Control and Prevention Web-based Injury Statistics Query And Reporting System (WISQARS), which contains cause- and intent-specific fatality data based on International Classification of Diseases version 10 codes and population size data from 1999 to 2016 (3). Based on the State Firearms Law Database (12), we determined that three states – Missouri, South Carolina, and West Virginia – implemented changes in age of handgun sales policies between 2004 and 2011, the period that allowed for at least five years of data prior to and following each of these state policy changes.

We used a difference-in-differences approach to compare changes in all-cause suicide fatalities in policy-change states in the five years prior to and following policy changes to changes in all-cause suicide fatalities over the same time period in comparison states (15,16). A key strength of difference-in-differences models is the inclusion of state fixed effects that control for each state. The state fixed effects control for baseline differences in levels of suicide fatalities between states and for all time-invariant state characteristics, such as historical differences; the analysis therefore focuses only on within-state changes in suicide fatalities over time. We conducted the main difference-in-differences analysis among those aged 18 to 20 years, who were affected by the policy changes. As a falsification test, we repeated the analysis among those aged 13 to 17 years, who were not directly affected by policy changes (we did not make comparisons to those older than 20 years because we expected them to be affected by other changes in firearms policies that would not affect those not eligible to purchase firearms). We also evaluated firearm-specific and non-firearm suicide fatalities.

An important requirement for difference-in-differences analyses is that there are parallel trends in the outcome in the period prior to the policy change in policy-change states and non policy-change states; the corollary is that these trends would continue to be similar in the absence of a policy change.

Sample

The sample was the full population of adolescents aged 13 to 20 years old in each of the three states with policy changes and in neighboring comparison states. We selected all neighboring states as comparison states for each policy-change state to avoid making subjective choices about comparison states; we did not choose comparison states based on covariate characteristics because this can bias difference-in-differences estimates (17). In the cases where a state neighbored two of the policy-change states, we assigned the given state to the policy-change state with fewer neighboring states. We assigned Tennessee, a neighbor of Missouri and a near-neighbor of South Carolina, to South Carolina because the state had only two direct neighbors. The result was the following three groups, with the policy-change states listed first: Group 1 –

Missouri – Arkansas, Kansas, Illinois, Iowa, Nebraska, and Oklahoma; Group 2 – South Carolina – Georgia, North Carolina, and Tennessee; and Group 3 – West Virginia – Kentucky, Maryland, Ohio, Pennsylvania, and Virginia. We formally evaluated whether the comparison states satisfied the parallel trends assumption relative to policy-change states (15). We used annual suicide fatality rate data from each state in the analysis for those aged 18 to 20 years and separately for those aged 13 to 17 years.

Data

The main exposure of interest was living in a state with a policy in place requiring firearm purchasers to be aged 21 years or older (hereafter referred to as "age 21 handgun sales policies"). In August 2007, Missouri implemented a policy lowering the age of handgun sales from 21 to 18 years when it repealed a decades old law, Section 571.090. In April 2008, South Carolina implemented a policy lowering the age of handgun sales from 21 to 18 years with the passage of the 2008 South Carolina Laws Act 192 (H.B. 4364). In contrast, in 2010, West Virginia amended Section 67-7-10 to restrict unlicensed firearm sales to the same age limits as licensed firearm sales, thereby limiting purchaser age to 21 years. We considered the policy change period to begin in the calendar year of policy implementation in each state.

The main outcomes were all-cause, firearm, and non-firearm suicide fatality rates per 100,000 adolescent person years, based on the CDC WISQARS database. Suicide fatality totals of less than 10 in a given state and year were suppressed to protect privacy (3). To address these suppressed values, we used the average of total suicide fatalities in the missing year and the following year for both years unless the following year was in a different policy period, in which case we used the average of the missing year and the prior year.

At the state level, we controlled for the proportion of suicide fatalities among those aged 21 or older due to firearms, poverty, and unemployment. We used the proportion of suicide fatalities among those aged 21 or older due to firearms as a proxy for changes in state household firearm ownership, a common approach (18) given that US law bans a federal registry of firearm sales (19) and state variability is use of the

National Instant Criminal Background Check System (NICS). To measure state-level poverty, we used United States census small area estimates of the proportion of the population each state living in poverty each year (20). To measure state-level annual unemployment, we used the mean of monthly data on state unemployment from the Bureau of Labor Statistics (21). We did not control for other state characteristics that we did not expect to change during the study period because we included in our analysis state fixed effects that would account for all time-invariant state characteristics. We did not use data on individual characteristics due to data suppression rules (3).

Analysis

We first evaluated whether the difference-in-differences parallel trends assumption was met prior to policy changes for suicide fatalities among those aged 18 to 20 years and aged 13 to 17 years. To formally test for parallel trends, we estimated the main regression model with an interaction term for being in a policy-change state and a continuous variable for calendar year prior to the policy period in each group.

We estimated a linear regression model with the rate of suicide fatalities per 100,000 separately with adolescents 18 to 20 and adolescents 13 to 17 years. We chose a linear regression model due to evidence that maximum likelihood models underestimate standard errors in the presence of fixed effects (22). In addition to the main indicator of interest – living in a policy change state during the period when handgun sales were restricted to those aged 21 or older – we controlled for living in a policy change state, for the time period of age 21 handgun purchase policies, for state and year fixed effects that controlled for each state and year, and for time trends specific to each three-state group. We also controlled for state characteristics that changed over time, including the proportion of adult suicide fatalities due to firearms and state poverty and unemployment rates; the state fixed effects controlled for any time-invariant state characteristics. We clustered standard errors by state.

Difference-in-differences models with a small number of groups can lead to underestimation of standard errors (23). To precisely estimate the p-value of the main analysis, we ran 1000 permutations of the main analysis. We created six additional groups of neighboring states, randomly selected three of the groups of states to include in each permutation, and randomly selected a state and year of policy change from within each group in keeping with the timing of policy changes in the main analysis (e.g. policy changes in 2007, 2008, and 2010). Based on the distribution of t-statistics from this analysis, we calculated the likelihood of observing a t-statistic with an absolute value greater than that estimated in the main analysis.

We conducted analyses separately evaluating the association between handgun purchase age policies and firearm-specific and non-firearm suicide fatalities to determine whether reductions in firearm-specific suicide fatalities drove the relationship between age 21 handgun policies and adolescent suicide attempts.

We conducted multiple sensitivity analyses. To ensure the analysis was not sensitive to the time period in which the study was conducted, we repeated the main analysis over six years prior to and following policy changes. To ensure the analysis was not sensitive to the choice of comparison states, we also compared policy-change states to all other states.

Findings

We describe the demographic characteristics of adolescents in the three states with age of handgun purchase policy changes and those of adolescents in the comparison states in Table 1. Adolescents in the three policy-change states were similar to those in the comparison states with regard to sex, race, and age. Just over three quarters of those living in both groups were white, 21% of individuals in both groups were black, and fewer than 5% of individuals were Asian, Pacific Islander, or Native American.

For the difference-in-differences analysis, we first determined that the parallel trends requirement was satisfied, and there were not statistically significant differences in time trends in suicide fatalities among

those aged 18 to 20 years in the policy-change states or in the comparison states prior to policy changes taking place (0.3 suicides per 100,000 person years; 95% CI: -0.2 to 0.8 suicides per 100,000 person years, Appendix Table 2 and Appendix Figure 1). There were also parallel trends in suicide fatalities among those aged 13 to 17 years (-0.3 suicides per 100,000 person-years, 95% CI: -0.7 to 0.1 suicides per 100,000 person years) in policy-change relative to comparison states.

The suicide fatality rate for adolescents aged 18 to 20 years in policy-change states was 12.4 per 100,000 person-years during the period of age 18 handgun purchase policies, as depicted in Table 2 and Figure 1, with 6.6 (53%) of suicide fatalities per 100,000 person years due to firearms. There were 2.6 fewer suicide fatalities per 100,000 person-years during the time period of age 21 handgun purchase policies among those aged 18-20 years in policy-change states, compared to 0.6 more suicide fatalities per 100,000 person-years among adolescents age 18 to 20 in the comparison states and a change in the suicide fatality rate among adolescents aged 13 to 17 years of less than 0.1 fatalities per 100,000 person-years in both the policy-change states and comparison states. In the difference-in-differences analysis adjusting for covariates, age 21 handgun sales policies were associated with a decline in suicide fatalities of 2.7 per 100,000 person-years among adolescents aged 18 to 20 years (95% confidence interval [CI]: -4.1 to -1.4 per 100,000 person-years, permutation-adjusted p-value = 0.02, Appendix Table 2). Among adolescents aged 13 to 17 years, age 21 handgun sales policies were not associated with a decline in suicide fatalities (0.6 suicides per 100,000 person-years, 95% CI: -0.5 to 1.6 suicides per 100,000 person-years, Appendix Table 2).

The decline in the suicide fatality rate associated with age 21 handgun sales policies was equivalent to a 22% (95% CI: 7% to 36%) reduction in suicide fatalities in the three policy-change states relative to the age 18 handgun purchase time period. With 1160 suicide fatalities among 7,772,629 adolescents aged 18 to 20 years in the 35 states without age 21 handgun sales policies in 2016 (3), such a relative reduction would be equivalent to 249 (95% CI: 77 to 420) fewer suicide fatalities among adolescents aged 18-20 years old each year across the US.

In the cause-specific analysis, age 21 handgun sales policies were associated with reduced firearm suicide fatalities (-2.3 per 100,000 person-years, 95% CI: -3.6 to -1.0 per 100,000 person-years, permutation-adjusted p-value = 0.04, Table 3 and Appendix Table 3). Age 21 handgun sales were not associated with reduced non-firearm suicide (-0.5 per 100,000 person-years, 95% CI: -2.0 to 1.0 per 100,000 person-years).

The main results were consistent when we included 6 years of data prior to and following policy changes overall (-2.9 suicides per 100,000 person years; 95% CI: -4.1 to -1.7 suicides per 100,000 person years, permutation-adjusted p-value: <0.01, Appendix Table 4) and with cause-specific suicide fatalities to ensure that the results were robust regardless of the time period in which the study was conducted. The results were also consistent when we compared policy-change states to all other states overall (-2.8 suicides per 100,000 person years; 95% CI: -3.4 to -2.2 suicides per 100,000 person years, p-value: <0.01, Appendix Table 5) and with cause-specific suicide fatalities to ensure the analysis was robust to different comparison groups.

Discussion

Suicide fatalities have been increasing in the US, particularly among adolescents (1). Healthy People 2020 has, as one of its goals, reducing suicide fatalities by 10 percent (24). We provide novel evidence that limiting handgun sales to those aged 21 or older was associated with 2.7 fewer suicide fatalities per 100,000 person-years among adolescents aged 18 to 20 years old, or a 22% relative reduction in the suicide fatality rate, exceeding the Healthy People 2020 goal for those aged 18 to 20 years. Such a change would translate into 249 fewer suicide fatalities among adolescents aged 18 to 20 years across the United States each year. These findings are consistent with prior evidence that increased access to firearms through greater household firearm ownership is associated with increased suicide fatalities (8,9) and with other estimates of means restriction of common means of suicide (25–27).

With 53% of suicide fatalities due to firearms in the age 18 handgun sales period, a 22% reduction in overall suicide fatalities due to age 21 handgun sale policies is plausible and supported by the other analyses. While most handgun sales are from licensed dealers, youth who are too young to purchase handguns from licensed dealers may specifically seek out handguns from unlicensed dealers affected by the policy changes that were the focus of this study. The cause-specific analyses supported a link between age 21 handgun sales policies and reduced firearm-specific suicide fatalities, while age 21 handgun sales policies were note associated with non-firearm suicide fatalities.

The strengths of the study include the use of data on the full populations of adolescents in relevant states and the difference-in-differences analytical design with careful attention to satisfying pre-period parallel trends assumptions. The difference-in-differences approach controls for absolute differences in suicide fatalities between states and captures whether changes in policies were associated with changes in suicide fatalities. The association between handgun sales to younger adolescents and increased suicide fatalities is supported by the finding of no relationship between changes in policies and changes in suicide fatalities among adolescents aged 13 to 17, whose handgun purchases were not affected by policy changes. The results of cause-specific analyses lends further support to the relationship between policy changes and firearm suicide fatalities, and we conducted a number of sensitivity analyses that were consistent with the main results.

The study also has limitations. Suicide fatalities are both a rare and a stigmatized outcome, and it is possible that fatalities due to suicidal intent were underreported (28). The CDC warns that state- and year-specific suicide fatality estimates can be unstable, though our analysis combines multiple states and years of data to provide a more stable analysis (3). The analysis focused on three states with policy changes; while it has strong internal validity, results may not be generalizable across the country. We could not control for important unmeasured adolescent characteristics associated with suicide, including socioeconomic status, parental marriage status, or sexual orientation, though these factors should only

affect the analysis if they changed over time within a state. We also could not control for unmeasured state characteristics that changed over time.

Conclusion

We found that state policies setting the age of handgun purchase to 21 years, such as those passed in Florida in Vermont in 2018, were associated with a 22% reduction in overall suicide fatalities among adolescents aged 18 to 20 years. Changing the age of handgun purchase policies from 18 to 21 across the country or in the 35 states without such policies may reduce adolescent suicide fatalities. Such a change is in keeping with public sentiment. In 2018, 67% of American adults reported support for more policies regulating firearms.(29) Federal and state policymakers may wish to consider policies that set the purchaser age for handgun sales to 21 years to reduce youth suicide fatalities.

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Table 1: Sample characteristics

	Person-years in policy-change states (Total = 5,331,295)		Person-years in comparison states (Total = 40,372,549)	
	N	%	N	%
Sex				
Female	2,597,010	49	19,678,925	49
Male	2,734,285	51	20,693,624	51
Race				
White	4,080,561	77	30,224,527	75
Black	1,123,115	21	8,310,507	21
Native American	33,935	1	497,076	1
Asian/Pacific Islander	93,684	2	1,340,439	3
Age				
18	1,750,970	33	13,386,138	33
19	1,807,600	34	13,573,868	33
20	1,772,725	33	13,412,543	33

Table 2: Reductions in all-cause suicide fatalities associated with age 21 handgun purchase policies by age group

	Policy-change states		Comparison states			
	Age 18 handgun purchase period	Age 21 handgun purchase period	Age 18 handgun purchase period (in policy-change states)	Age 21 handgun purchase period (in policy-change states)	Change in suicide fatality rate	95% confidence interval
Adolescents aged 18 to 20 years						
Suicide fatalities	339	255	2071	2128		
Person-years	2,733,933	2,597,362	20,431,594	19,940,955		
Suicide fatality rate per 100,000 person years	12.4	9.8	10.1	10.7		
Difference: Age 21 sales - age 18 sales	-2.6		+0.6		-2.7**	-4.1 to -1.4
Adolescents aged 13 to 17 years						
Suicide fatalities	205	205	1474	1431		
Person-years	4,150,242	4,196,627	32,944,560	32,024,956		
Suicide fatality rate per 100,000 person years	4.9	4.9	4.5	4.5		
Difference: Age 21 sales - age 18 sales	<0.1		<0.1		0.6	-0.5 to 1.6

Note: **Permutation-adjusted p-value <0.05.

Table 3: Reductions in cause-specific suicide fatalities associated with age 21 handgun purchase policies among those aged 18 to 20 years

	Policy-change states		Comparison states			
	Age 18 handgun purchase period	Age 21 handgun purchase period	Age 18 handgun purchase period (in policy-change states)	Age 21 handgun purchase period (in policy-change states)	Change in suicide fatality rate	95% confidence interval
Firearm suicide fatalities						
Suicide fatalities	181	129	978	1047		
Person-years	2,733,933	2,597,362	20,431,594	19,940,955		
Suicide fatality rate per 100,000 person years	6.6	5.0	4.9	5.1		
Difference: Age 21 sales - age 18 sales	-1.6		+0.2		-2.3**	-3.6 to -1.0
Non-firearm suicide fatalities						
Suicide fatalities	158	126	1093	1081		
Person-years	2,733,933	2,597,362	20,431,594	19,940,955		

Suicide fatality rate per 100,000 person years	5.8	4.9	5.4	5.4		
Difference: Age 21 sales - age 18 sales		-0.9		<0.1	-0.5	-2.0 to 1.0

Notes: ****** permutation-adjust p-value<0.05

Figure 1: Suicide fatality rate by age and policy period in policy-change and comparison states